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Contents

In This Issue

Why this Journal? The historical reason is the initiative of O.V. Wells, Chief of the Bureau of Agricultural Economics, who felt that "... such a journal should prove as useful to agricultural economists and statisticians as similar journals have proved in other fields ..." In 1949, as now, a substantial fraction of agricultural economists and their social scientist allies were employees of, or cooperators with, the U.S. Department of Agriculture. A technical periodical should be the tool of the researchers to share ideas, challenges, successes, and failures with members of the profession and others intimately concerned with research results and reliability. This journal is such a tool for USDA's social scientists and the readers of their reports.

Books, bulletins, and brochures convey research information. But, journals provide continuity and connections. They provide a continuity of knowledge in an area of inquiry; journals are the profession's diary. They provide connections to other people, other fields, and other ways. If journals do their job right, readers will discover a concise map and itinerary of their profession's intellectual travels. In this issue, JAER places seven new destinations on its map, three articles and four book reviews.

Matt Rendleman's article on the economic impact of agrichemical reduction is the first stop on the itinerary. With a computable general equilibrium model, Rendleman analyzes the effect of an overall reduction (as against a specific chemical or crop) in agricultural chemicals. Beginning with an economy presumed to be in equilibrium, he identified an economywide loss in efficiency from the shock of chemical restriction. That loss in efficiency grew as chemical restrictions expanded. Small restrictions caused virtually no losses. When restrictions increased, so did losses in efficiency. Distributional effects depend upon the form of restriction (tax, production, or use) and market conditions (the relative power of manufacturers and farm producers). Over time, measures aimed at controlling chemicals increase the variability of farm prices, and, at modest levels of control, increase environmentally protective practices.

Ronald Babula and Robert Romain examine another type of restriction, on output rather than input. Their article asks whether the Canadian broiler market, which has strict supply and trans-border controls, can be influenced by the United States. They conclude that changes in the U.S. broiler industry are felt in Canada despite import restrictions. In general, however, the Canadian supply management program, perhaps with the help of some production consolidation, has insulated the Canadian market from U.S. price movements. The authors comment briefly on the use of vector autoregression for policy analysis.

LeRoy Hansen explores the effects of climate change on agricultural practices by posing the question: Do farmers respond to long-term changes in weather patterns? Hansen sought to determine whether the adjustments in management practices and input use, which are not normally included in plant growth models, affected yields. Cross-sectional data from 10 corn-producing areas substituted for longitudinal climate responses, which eliminated fortuitous technology changes. His conclusion: small modifications in farming practices accommodate climate differences and therefore do affect yields. The findings show that crop growth models could be improved by adding proxies for minor adaptations in farm practices.

A review of Mary Morgan's *History of Econometric Ideas* by Clark Edwards contains fascinating observations on the evolution of our economic analysis from Jevons's sunspots, through the "probability revolution" of the 1940's, to the collapse of the founding ideal of econometrics in the 1950's. That's right, collapse. Read Edwards to see how the story ends.

Geographic information systems are additional tools for economic analyses. GIS is still in its formative stages for economic analysis. David Moyer reviews a set of *Introductory Readings in Geographic Information Systems*, edited by Dona Peuquet and Duane Marble. This work contains background on the history and development of GIS that is particularly useful for beginners, but obsolescence is a problem because of the rapidly changing technology.

Neil Harl's *The Farm Debt Crisis of the 1980's* was printed by Iowa State Press in its historical memoirs series. The mixture of analysis and personal commentary troubles reviewers Douglas Duncan and Steven Koenig. Not satisfied with the book's inadequacies, they plump for continuing and much-needed empirical work in agricultural, and presumably financial, policy.

Only a special few of the Journal's readers will rush out for Isabelle Tsakok's *Agricultural Price Policy: A Practitioner's Guide to Partial-Equilibrium Analysis* upon reading Milton Ericksen's review. Those inquisitive few, however, may find her book a helpful shop manual for price analysis. You know who you are and what you must do, so read Ericksen's review and decide.

This issue is my last as economics editor. The editorship has been an interesting, satisfying experience, largely because of the many contacts with authors,

reviewers, and staff of the Journal. I want to express special appreciation to my two co-editors, Judith Latham and Jim Carlin, and to the editorial board members and staff assistants. Also, praise should go to those anonymous reviewers who have spurred the nonanonymous authors to produce better, sharper articles. Thank you.

I am pleased to introduce the new economics editors, James Blaylock and David Smallwood, who together bring many years of research experience to their new assignment. We are privileged to have them assume the responsibility for guiding the Journal. Welcome, Dave and Jim.

Gene Wunderlich

2415

Agrichemical Reduction Policy: Its Effect on Income and Income Distribution

C. Matthew Rendleman

Abstract. *When farm chemical use is restricted, gross farm income rises, but net income may fall. A 10-sector applied general equilibrium model was used to arrive at this assessment. Compared are a chemical use tax, an input restriction on chemicals, and a farm sales restriction imposed on input suppliers. The tax and sales restrictions reduce net income because of rising costs, while the input restriction holds the potential for raising net farm income.*

Keywords. *Farm chemicals, farm income, computable general equilibrium, input reduction.*

Whether or not clean water and food safety have been compromised by misuse or overuse of farm chemicals, the environmental impact of farm input use is now a public policy issue. Several studies have attempted to capture the effect of complete bans on certain chemicals on particular crops (see, for example, *10* and *11*), but any across-the-board restriction is likely to have economywide consequences.[1] Across-the-board restrictions would mandate reduced use of all chemicals rather than targeting individual chemicals for complete removal. Current regulations do not impose sweeping bans or even partial reductions in agrichemical use, but such proposals have been broached.

Approaches to chemical regulation are becoming more creative. At least 37 States have their own, often varied, laws regulating, for example, water quality. State policies range from taxing fertilizer to regulating practices and quantities of chemical use (*14*). Some reformers have advocated steep reductions in chemical use across the country, for example, a 50-percent reduction in chemical use (*12*). Some proposed national legislation tends to be more sweeping than past approaches.[2]

The economic consequences of a general reduction in chemical use, as opposed to a one-at-a-time, chemical-by-chemical reduction have not been thoroughly studied. A recent study (*8*) concluded that its exhaustive look at a complete chemical ban from agriculture was only a "first step" toward assessing the impact of the more likely imposition of partial reductions.

The purpose of this article is to determine the effects of an across-the-board reduction in chemical use, demonstrating how economic rents and burdens may be generated and distributed, and presenting policy alternatives that could change the distribution of these rents and burdens. In this study, "chemicals" refers to nitrogen and phosphorus fertilizers as well as pesticides. Although a complete model gives industry-by-industry price and quantity changes brought about by the reduction, I present these results only to provide a baseline from which to evaluate income and welfare changes.

The Model

Because the consequences of a sweeping agrichemical reduction will have consequences beyond the farm sectors directly affected, I used a computable general equilibrium (CGE) model. Hertel (*6*) summarizes the strengths of CGE analysis (for the case of a farm subsidy) with four general points:

- The CGE model explicitly acknowledges the finite resource base of the economy.
- The question of who foots the bill for the subsidy (or other distortion) cannot be sidestepped in a fully specified CGE model.
- The consumer's budget constraint, linking factor returns and uses of income, is modeled directly.
- There is a definitive check on the conceptual and computational consistency of the model.

In this analysis, a distortion, in the form of a quantity restriction on chemical use in agriculture, is placed in the producing sectors between the manufacturers and users of chemicals. The producing sectors are linked—laterally to one another through interindustry flows, backward to the resource base (owned by consumers), and forward to consumers by final demand. A straightforward approach traces down who really "foots the bill" for the distortion. The "conceptual check" on the consistency of the model also proved to be important, since rents generated by a partial ban—often overlooked in other analyses—must be received by someone.

The model employed includes 10 individual producing sectors, each making a single homogeneous product. The agricultural sector is disaggregated into three subsectors: a) feed grains and oilseeds b) poultry, dairy, and livestock, and c) other agricultural products, including fruits and vegetables. Nonagricultural sectors are: a) manufacturing, b) services, c) livestock processing, d) feed grain and oilseed processing, e)

Rendleman is an agricultural economist with the Resources and Technology Division, ERS.

[1]Italicized numbers in parentheses cite sources listed in the References section at the end of this article.

[2]Recent Senate and House versions of a bill establish tougher, so-called "negligible risk," standards for pesticide approval, permitting the Environmental Protection Agency to charge fees for its regulatory work.

other food processing, f) agricultural services, and g) chemical production. The principal block of data on which the economic model is built is a social accounting matrix (SAM) developed from data provided by the National Aggregate Analysis Section of the Agriculture and Rural Economy Division of the Economic Research Service.

The model can be fully described by the number of consumers and their utility structures, the number of producing sectors and their production functions, and the number and kinds of commodities. Consumers allocate their incomes to maximize the utility of consumption, and producers adjust production to maximize profit. In the perfectly competitive setting of the model, consumers and producers are assumed to be price-takers. The economic agents of the model, the domestic and foreign[3] consumers, are both owners of resources and consumers of final products. They receive income from the ownership of land, labor, and capital and spend it on final goods according to a constant elasticity of substitution preference structure.

The model must be solved in order to answer questions about the state of the economy before and after a change in a given policy variable, satisfying equilibrium conditions in all producing and consuming sectors simultaneously. I solved the problem numerically using Rutherford's (*15*) MPS/GE software, which has proven reliable in other research (see, for example, *3* and *13*).

The ease with which farmers are able to substitute the use of other inputs for chemicals is represented by the elasticity of input substitution parameters of the model. Land use is fixed by commodity group. Thus, corn land can be used in soybean production because they are both components of the "feed grains and oilseeds" sector, but corn land cannot be used to produce fruits and vegetables. Fixity of land by sector implies that, as the residual claimant of agricultural income (the factor that gets what is left of gross income after other costs have been paid), land will receive the greatest shock as agriculture is faced with increasing costs.[4] This study assumes current technology throughout the simulation, though within this technology substitution of inputs is permitted. A new technology could be considered a development that permits a new farming technique. Examples are as diverse as the development of pest-resistant plants, which would make insecticides less necessary, or nitrogen-fixing grasses, which would reduce the need for nitrogen fertilizers. The study assumes that the technology observed over the past several years would continue to be employed in the face of chemical restrictions.

The only exception to competitive pricing comes as the restriction to agricultural chemicals is put in place. As agricultural chemicals are restricted, the right to sell these chemicals becomes more important, commanding a price. This right, which is not a product as such, contributes to a kind of monopoly profit. As the regulation of agricultural chemicals becomes increasingly restrictive, farmers both change the way they produce, substituting the least expensive input mix available, and limit production. The upshot is higher prices and fewer farm products on the market. With each increase in chemical restrictions, a new set of prices throughout the economy ensures that the flow of goods maximizes firm profits and consumer utility. All prices are relative to the numeraire good, domestic manufactures, which was chosen for this role because it was likely to change least in response to a chemical use prohibition.

Model Results

When agriculture undergoes a 75-percent chemical reduction, output drops and commodity prices rise (table 1). (Output and price effects are endogenous and dependent on the elasticity of substitution parameters.) The greatest impact is in the farm sectors, particularly those that rely most heavily on chemicals. Thus, the output of the feed grains and oilseeds sector declines more than the output of the livestock sector. The processing sectors use some "agricultural" chemicals, but the reduced quantities of farm products available as inputs cause the primary output decline in these sectors. The reduced output generally triggers higher prices throughout the economy. (The price of services drops slightly compared with manufacturing

Table 1—Price and output change, by industry, for a 75-percent reduction in use of agricultural chemicals[1]

Sector	Output change	Price change
	Percent	
Manufacturing	–0.8	0
Services	–.3	–.5
Livestock processing	–2.4	5.9
Feed grain/oilseed processing	–7.9	10.8
Other food processing	1.3	2.0
Livestock/poultry/dairy	–5.2	10.2
Feed grains/oilseeds	–20.4	25.1
Other agriculture	–12.9	15.0
Agri-services	–11.3	19.0
Factors of production:		
Labor	0	–0.7
Capital	0	–1.1
Fixed livestock inputs	0	–11.0
Grain land	0	–21.4
Other agricultural land	0	–33.9

[1]All price changes are relative to the numeraire good, domestic manufactures.

[3]A complete set of foreign goods is produced along a constant elasticity of substitution production possibilities frontier. Some of these goods are used directly by the foreign consumer and some are traded. Trade takes place via the Armington assumption, where domestic and foreign goods are less than perfect substitutes for each other. The budget constraint also ensures that the balance-of-payments requirement is met.

[4]Farm programs that govern land use (such as conservation reserve) are not directly modeled.

simply because of a slightly greater use of now cheaper inputs.) Because of the loss of production efficiency, returns to factors of production are generally lower, resulting in reduced income.

The chemical production sector's output, not included in the table, actually falls 71.2 percent—not quite 75 percent, because exports are not curtailed. The price, better thought of as the value of the marginal product of chemicals in agriculture, rises almost sevenfold for the shortrun equilibrium modeled in this exercise.

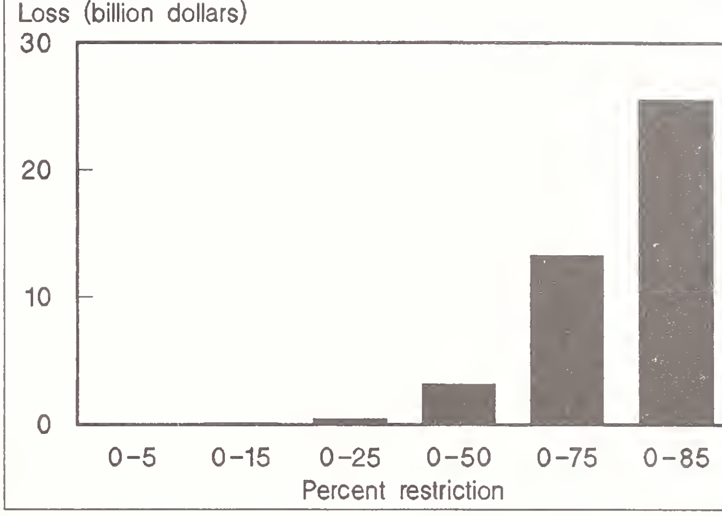
Economywide Burden

When a chemical restriction is introduced into the 10-sector CGE model, the first effect is a loss of production efficiency. The economy, assumed to be at an optimum point in the base case, sees the removal of chemical inputs lower the marginal productivity of such other inputs as land and labor. This follows from what Sakai (*16*) calls the "normal" case. In a practical sense, this means that labor without chemicals (for example, walking beans with a hoe) is not as effective as labor with chemicals (for example, applying post-emergence herbicide eight rows at a time at 10 miles per hour), or that land without fertilizer is not as productive per acre as land with fertilizer. Farmers now use more nonchemical inputs per unit of production. They use fewer nonchemical inputs overall, as the less efficient, higher cost production techniques drive up output prices and drive down the output quantities demanded.

The inefficiency caused by the restriction causes a drop in agricultural output and a consequent rise in prices. An appropriate way to quantify the overall loss to society is by measuring the equivalent variation of the chemical restriction at various reduction levels. Equivalent variation (E.V.)[5] provides a dollar value for the change in utility. For the domestic economy, losses measured in E.V. increase at an ever faster rate (fig. 1), a finding consistent with various cost-of-compliance studies.[6]

The elasticity of change in this drop in E.V. with respect to the restriction goes from essentially 0 up through the 15-percent restriction level to over 9 between the 75-percent and 85-percent restriction levels. Justifying a low level of restriction would be less

Figure 1
Equivalent variation (measured as a positive value) associated with increasing chemical restriction



difficult than higher reductions, when each percentage point of chemical reduction produces over $1 billion worth of societal burden. The appropriate level of reduction would equate the cost of implementation (calculated here as equivalent variation) with the benefits gained by that level of reduction. It is the benefits of the restrictions that are most difficult to quantify. Pimentel and others (*12*) estimated the annual indirect public health costs of pesticides at $2-$4 billion. This criterion alone would make the appropriate level of reduction less than 50 percent. However, even this measure is more complicated than it appears. In the first place, all the $2-$4 billion benefit would not likely be gained at the 50-percent reduction level. Second, other benefits, such as reduced ground-water leaching of nitrates, are not accounted for. Estimates of societal benefits across a range of reduction levels are needed to arrive at the correct level of chemical reduction.

Distributional Effects

The degree to which the various industries decline as chemicals are withdrawn comes from the cost share of chemicals used in production and the elasticity of substitution between chemicals and other inputs. For these reasons, industrial contractions are generally most severe in the farm sectors, but the higher costs and reduced outputs also pass through to the downstream industries, first to food processing and then to the less agriculturally intense sectors.

Because the total demand for agricultural products is inelastic, total revenue in agriculture climbs. Much of the rise is just gross income spent on more expensive variable inputs. Returns to land drop. Who ultimately pays the price for restriction depends on the change in the value of assets, which in turn greatly depends on

[5] $E.V. = \frac{U_1 - U_0}{U_0} I_0$. Where U and I are utility and income levels, respectively, subscripts are 0 for initial values and 1 for post-change values. (See *5*.) McKinzie and Pearce (*9*) offer a strong argument for the use of equivalent variation as a measure of welfare change. However, for those who prefer compensating variation, calculated values were not significantly different.

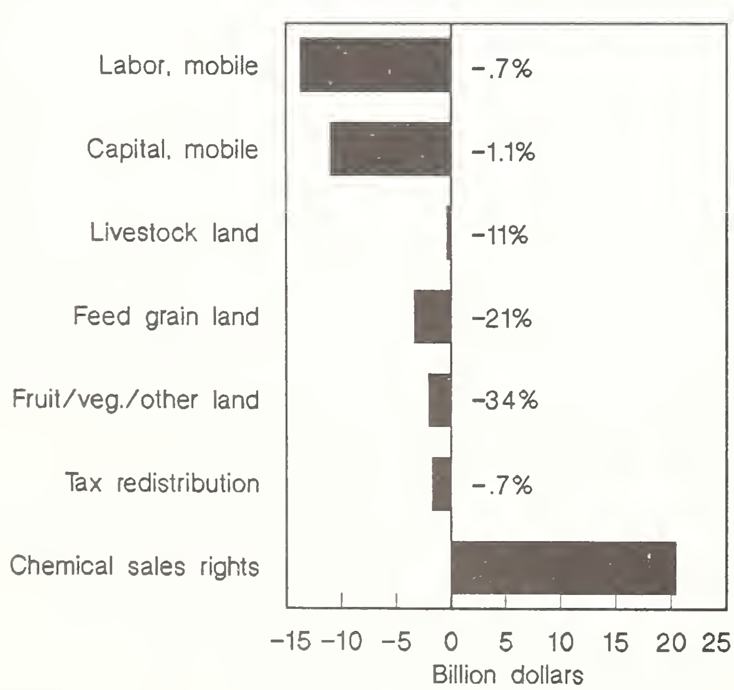
[6] Baumol and Oates (*2*) provide a general discussion of this phenomenon under the heading "By How Much Should We Reduce Pollution?" Several studies are cited as evidence of increasing costs of compliance.

how the reduction policy is implemented. Measuring this change determines the distributional effects of the restriction. To determine how a particular agent will fare, we must know what part of each asset the agent holds. Asset values tend to decline when they are in an industry that is an intensive user of agricultural chemicals and when they cannot be transferred out of that industry. The land rental rate, as an example of returns to a nonmobile resource, is determined by its derived demand and its availability. Removing one input usually lowers the value of the marginal product (VMP) of the others due to the complementarity of inputs. Thus, chemical reduction lowers the VMP of land in agriculture through the lower marginal physical product (MPP, the change in the physical output component of VMP), and reduces returns. The drop in the rental rate is moderated, but in this case not overcome, by rising agricultural prices, the other component of VMP. For a factor like labor, this drop in returns is tempered by mobility, and labor moves out of agriculture.

The 75-percent chemical restriction most influences returns to factors dedicated to agriculture, mostly land (fig. 2). The absolute level of returns declines more for the mobile factors, but the percentage drop, and thus the impact felt, is far greater for owners of land and agriculture-only factors of production.

As the use of chemicals is restricted, the dwindling amount of chemicals becomes more valuable per unit of production. This results in a difference between the cost of producing chemical inputs and their value in production. In addition to physical factors of production, marketing rights begin to acquire value, having the potential (for a restriction level somewhere short of complete) to more than offset lost farm income as represented by returns to land. Whether these rents go to farmers or others is largely a matter of public policy.

Figure 2
Change in asset values with a 75-percent restriction in farm chemical use



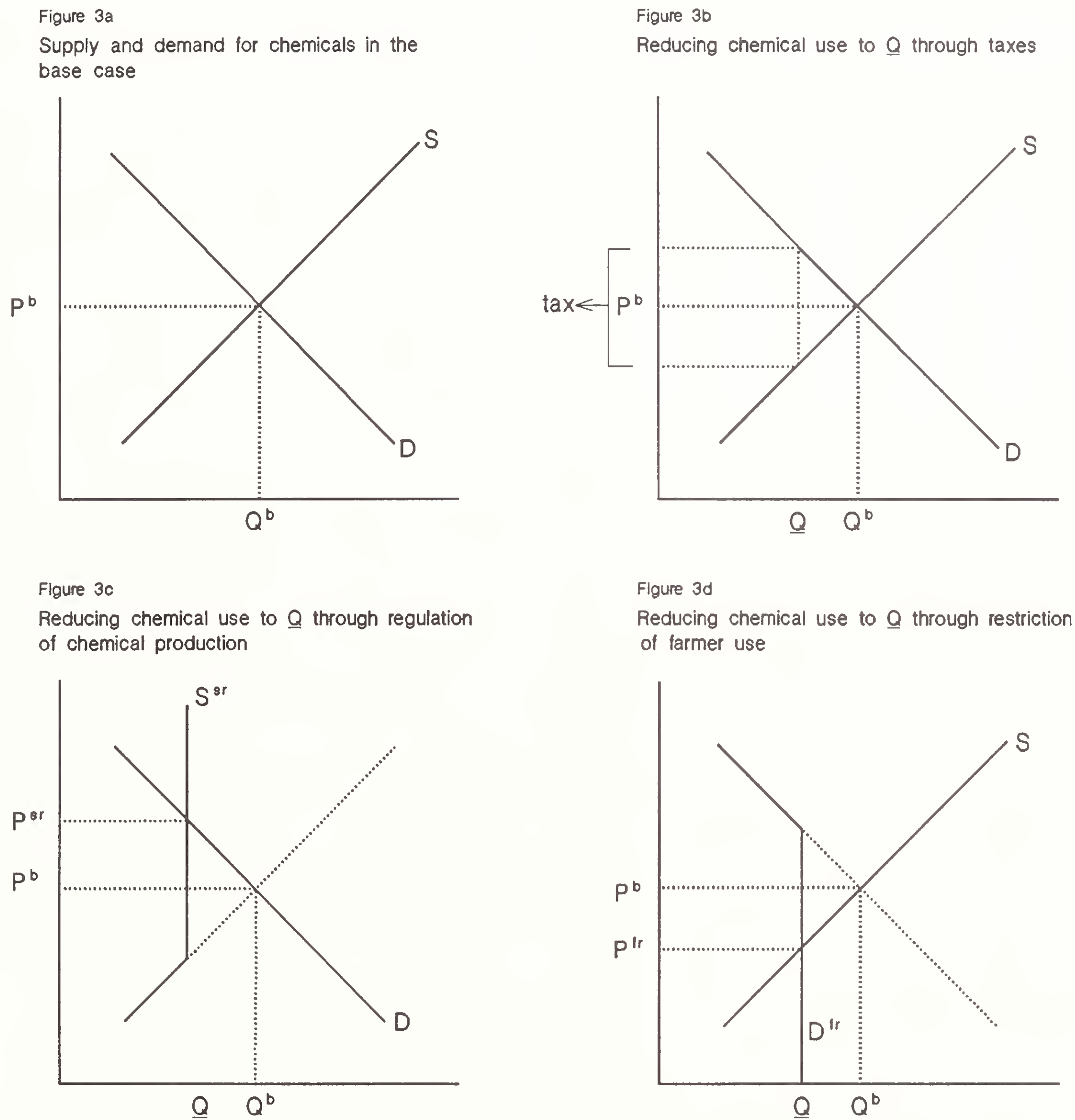
A number of policy options can reduce the use of chemicals in agriculture. Assuming that a policy aimed at chemical inputs is chosen, the likely instruments would be a tax on chemicals or a mandated reduction in chemical use, called a quantity restriction for simplicity. Either policy introduces a wedge between supply and demand that could reduce input use to a targeted level.

To understand the economic rent distribution, it is helpful to abstract from the general equilibrium effects. Figure 3 illustrates, in a partial equilibrium setting, how a policy goal of chemical reduction could be achieved through a use tax, a restriction on farmer input use, or a quantity restriction on chemical manufacturers' output.

In the unrestricted case (fig. 3a), supply and demand converge at price P^b and result in quantity Q^b being sold and used. If, from a public policy point of view, the appropriate quantity to be used is $\underline{Q}$, then several options are available. (Though the diagrams in figure 3 appear much smaller, a 75-percent restriction is used in the general equilibrium examples which follow, unless otherwise noted.) The tax in figure 3b simultaneously drives up the price farmers must pay and drives down the price suppliers receive (relative burdens being determined by elasticities). Although the general equilibrium effects make the model results more complicated than reflected in the diagram, the size of this transfer is estimated to rise to $20 billion by the time 75 percent of the chemicals now used are withdrawn from the market.

Figure 3c assumes that, whatever policy is implemented, chemical producers can behave as monopolists. Call this a "seller restriction." Suppliers are allowed to cut back their output to $\underline{Q}$ and extract the resulting rents from farmers. Price, $\overline{P}^{sr}$, is then determined by demand. Though this extreme outcome (the entire $20 billion going to chemical producers) is unlikely, it serves to establish one end of the welfare spectrum brought about by chemical policy. This seller restriction would tend to benefit chemical companies if they had exclusive marketing rights over chemicals remaining on the market, and if inventory stockpiles were not a problem, and if no close substitutes were developed rapidly. In this situation, most of the burden falls on farmers. Chemical producers would be better off since the price rises due to the restriction are greater than the losses from reduced sales.

Figure 3
Reducing farm chemical use by 75 percent: Effects depend upon mechanism used

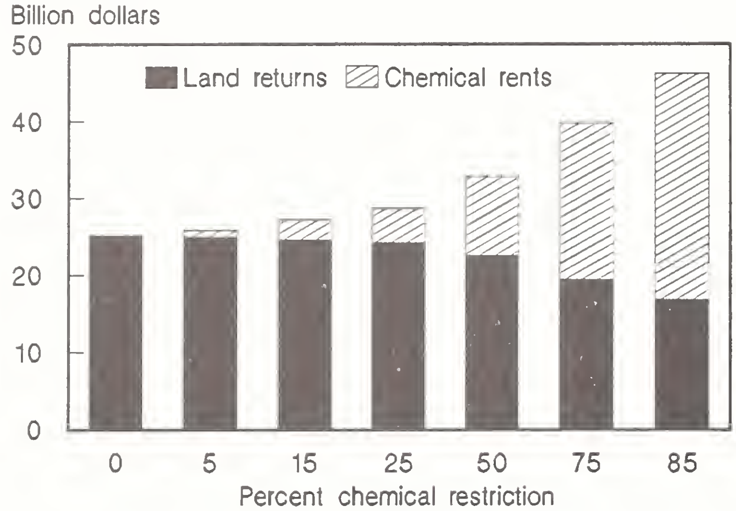


This figure is not to scale and does not include the shifting of supply and demand that takes place with the changes. Except for the distributional issue, taxes, and quantity restrictions are assumed to have the same effect. Quantity restrictions and taxes are used to reduce chemical use to $\underline{Q}$.

Figure 3d shows farmers who are able to cut back on chemical use and behave as monopsonists. The demand curve becomes perfectly inelastic at $\underline{Q}$ and the price burden falls on the chemical producers. This "buyer quota" scenario occurs only in the unlikely event that chemical manufacturers do not reduce supply in the face of these restrictions, a feasible case if farmers are permitted to cut back on particular chemicals to reduce overall use, or if manufacturers' stocks were burdensome. The gain of $20 billion, if it went to farmers would more than offset the $5 billion lost by diminished asset returns. If monopsony rents accrued to farmowners, total returns would rise despite the drop in returns to land services. Figures 3c and 3d represent bounds on farmer and chemical producer burdens, respectively. The likely actual outcome will depend upon the relative strength of the factors favoring farmers or chemical manufacturers.

Figure 4 shows the change in total revenues to land and "marketing rights" and the change in composition. As the restriction increases (moving to the right on the horizontal axis) returns to land services (measured in billions of 1982 dollars on the vertical axis) fall, but, if purchasing rights are the property of farmers, overall returns rise. Researchers may reach different conclusions about farm income effects even with otherwise similar models and assumptions, if their ideas about chemical rents differ.

Figure 4
Potential revenue changes for land and chemicals with varying levels of chemical restriction



Dynamic Effects[7]

Assuming that the distributional differences between a quantity restriction and a tax can be compensated, other considerations can cause the equivalence to break down. For example, exogenous shifts in supply or demand will result in different incidence patterns between the quantity restriction and the tax. Though the supply of chemicals is likely to be quite stable from one period to the next, shifts in derived agricultural demand, due to weather patterns or other considerations, are likely. In general, policies that lower farm input prices also bring greater price variability.[8] Chemical restriction policy then has the potential to affect not only prices but price variability. Price variability is policy dependent, and where variability is increased, welfare most likely falls for both producers and consumers (*7*).

Incentives and Product Development

In the past, chemicals have been restricted on a case-by-case basis, allowing the use of substitutes as the targeted chemical was phased out. Economic studies have predicted moderate impacts from bans of this type (*10, 11*) because many pesticides have one or more close substitutes. This approach to restriction also encourages a search, through research and development, for more acceptable substitutes. The current study approaches the problem under the assumption that all chemicals will be reduced across the board. This produces large aggregate effects, more than $13 billion lost to the domestic economy and up to $53 billion redistributed at the 75-percent restriction level alone. The aggregate effects occur because farmers, although able to substitute fairly easily away from particular chemicals, are not able to substitute as easily for chemicals as a group. This implies a small elasticity of substitution between chemicals and other inputs. In the long run, this elasticity would be larger and the price and output effects would diminish. Also, a more drastic across-the-board cut could halt the development of new chemical products regardless of their merit. Though properly handled in a dynamic model, the matter of incentive to develop safer products differs between an across-the-board chemical reduction and a case-by-case risk, or hazard-based criterion reduction. Development of new, more environmentally benign chemicals, like those developed for cotton after the banning of DDT, might actually be increased under the latter type of restriction since there would still be a market for chemicals that meet the necessary criteria. Of course, no incentive would exist for this development in the case of a total chemical ban. On the other hand, the development of non-chemical technology might be speeded up. Genetic engineering may introduce such revolutionary changes as corn plants with the ability to fix atmospheric nitrogen (like legumes), thus making the application of nitrogen fertilizers less necessary. Other genetic engineering possibilities include inducing vegetable plants to produce bacillus thuringiensis toxins (*4*), negating the need for many insecticides. Each of these pest or fertilizer developments carries its own type of risk, which must be considered.

Conclusion

How the economic burden of chemical reduction will be divided depends on the type of reduction policy enacted. The loss of production efficiency caused by the chemical reduction will be borne by society regardless of how the policy is implemented. This loss becomes disproportionately larger as the restriction is made more severe, maybe as high as $25 billion. The principle of equating marginal cost to marginal benefit provides a rule for determining how large to make the overall cutback in chemical use. The distributional effects, caused by the shifting value of factors of production in the economy and the possible creation of new monopoly rights, are determined almost entirely by the choice of policy instruments—whether the Government collects the rents generated or whether it allows chemical companies to behave as monopolists or farmers to behave as monopsonists. In the latter case, monopsony rents are expected to more than offset lost factor returns. The choice of policy instruments ultimately depends on what redistribution of wealth society finds preferable.

Though the CGE model does not directly deal with other time-related effects of chemicals reduction policy

[7]Dynamic as used here means simply any changes through time.

[8]This possibility has been noted in the trade literature comparing import tariffs and quotas. Analysis available from the author demonstrates these results using a simplified version of such work by Bale and Lutz (*1*).

that might be expected, analysts should consider them. Variability of prices for chemicals (and thus farm products) can be affected by the type of policy employed. Policies that lower farm input prices tend to bring greater price variability. The incentive to develop more environmentally benign chemicals may be inhibited by a total ban but possibly encouraged by more mild restrictions.

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245

Canada's Broiler Supply Management Program: A Shield From U.S. Price Volatility?

Ronald A. Babula and Robert F.J. Romain

Abstract. *Canadian broiler price responses to increases in U.S. prices either have lessened in magnitude and duration or have been eliminated since Canada's broiler supply management program began in 1979. The authors used monthly vector autoregressions of U.S. and Canadian broiler prices (farm and retail), estimated for periods before and after Canada introduced its broiler supply management program, to arrive at the results. The analysis also demonstrated that data-oriented, time-series statistical methods are useful in policy analysis when focusing on a policy's dynamic aspects, contrary to the opinion of some researchers.*

Keywords. *Canadian broiler supply management, corn and broiler prices, vector autoregression, dynamic price transmissions.*

Canada implemented a national broiler supply management program (hereafter, the Canadian NSM program) in 1979 to augment its existing provincial programs and to insulate Canadian broiler prices from U.S. broiler price fluctuations.

Since the U.S./Canadian free trade agreement (FTA) in 1989, the methods and the success of the Canadian broiler program have been scrutinized from both sides. Policymakers involved with the FTA need to know how, and to what extent, Canada's broiler program has impeded U.S./Canadian broiler price signals, and hence broiler trade, even though the FTA exempts broilers. This information is important because (1) the FTA aims eventually to liberalize agricultural trade generally; (2) the FTA recently instituted a modest liberalization (increase) in the Canadian broiler import quota; and (3) Canadians and Americans, already in a "trade-liberalizing" frame of mind, may further liberalize U.S./Canadian broiler trade again in the future (see *7*, *8*, *9*).[1] Any future liberalization of this broiler trade requires quantifying the price signal impediments of such existing policy barriers as the Canadian NSM program. Further, an understanding of how the existing Canadian NSM program has succeeded in blocking U.S./Canadian cross-border broiler price interchange would provide useful information for analysts in other nations that are considering similar policies.

This paper focuses on whether, and to what degree, Canadian broiler supply measures have succeeded in blocking out American broiler price influences on Canadian broiler prices. Vector autoregression (VAR) techniques are used to glean empirical regularities from monthly data on four broiler prices converted to deflated Canadian dollars: U.S. farm price (USFP); U.S. retail price (USRP); Canadian farm price (CFP); and Canadian retail price (CRP). Monthly VAR models of the price transmission mechanism are estimated for an early period before (January 1967-December 1978), and for a recent period after (January 1980-December 1987), introduction of national supply management (the early and recent models, respectively). By comparing the early and recent models' dynamic characteristics of U.S./Canadian broiler price transmissions, we discern how such dynamic price transmissions and cross-border price relationships have changed since the the 1979 implementation of Canada's NSM program.

Estimated VAR Model, Data Sources, and Scenario Design

The literature is replete with summaries of VAR econometrics, so another such summary is not presented here. For background information on VAR econometrics, see Sims (*21*) and Bessler (*5*).

The following VAR model was estimated for the early and recent periods:

$$\begin{aligned} USFP_t = {} & a_{UF,0} + a_{UF,T}{*}TRD + a_{UF,1}{*}USFP_{t-1} \\ & + \ldots + a_{UF,k}{*}USFP_{t-k} + a_{UF,k+1}{*}USRP_{t-1} \\ & + \ldots + a_{UF,2k}{*}USRP_{t-k} + a_{UF,2k+1}{*}CFP_{t-1} \\ & + \ldots + a_{UF,3k}{*}CFP_{t-k} + a_{UF,3k+1}{*}CRP_{t-1} \\ & + \ldots + a_{UF,4k}{*}CRP_{t-k} + A_t \end{aligned} \tag{1}$$

$$\begin{aligned} USRP_t = {} & a_{UR,0} + a_{UR,T}{*}TRD + a_{UR,1}{*}USFP_{t-1} \\ & + \ldots + a_{UR,k}{*}USFP_{t-k} + a_{UR,k+1}{*}USRP_{t-1} \\ & + \ldots + a_{UR,2k}{*}USRP_{t-k} + a_{UR,2k+1}{*}CFP_{t-1} \\ & + \ldots + a_{UR,3k}{*}CFP_{t-k} + a_{UR,3k+1}{*}CRP_{t-1} \\ & + \ldots + a_{UR,4k}{*}CRP_{t-k} + B_t \end{aligned} \tag{2}$$

$$\begin{aligned} CFP_t = {} & a_{CF,0} + a_{CF,T}{*}TRD + a_{CF,1}{*}USFP_{t-1} \\ & + \ldots + a_{CF,k}{*}USFP_{t-k} + a_{CF,k+1}{*}USRP_{t-1} \end{aligned} \tag{3}$$

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[1]Italicized numbers in parentheses cite sources listed in the References section at the end of this article.

$$+ \ldots + a_{CF,2k}{}^{*}USRP_{t-k} + a_{CF,2k+1}{}^{*}CFP_{t-1}$$
$$+ \ldots + a_{CF,3k}{}^{*}CFP_{t-k} + a_{CF,3k+1}{}^{*}CRP_{t-1}$$
$$+ \ldots + a_{CF,4k}{}^{*}CRP_{t-k} + C_t$$

$$CRP_t = a_{CR,0} + a_{CR,T}{}^{*}TRD + a_{CR,1}{}^{*}USFP_{t-1} \quad (4)$$
$$+ \ldots + a_{CR,k}{}^{*}USFP_{t-k} + a_{CR,k+1}{}^{*}USRP_{t-1}$$
$$+ \ldots + a_{CR,2k}{}^{*}USRP_{t-k} + a_{CR,2k+1}{}^{*}CFP_{t-1}$$
$$+ \ldots + a_{CR,3k}{}^{*}CFP_{t-k} + a_{CR,3k+1}{}^{*}CRP_{t-1}$$
$$+ \ldots + a_{CR,4k}{}^{*}CRP_{t-k} + D_t.$$

The variables USFP, USRP, CFP, and CRP are defined above. The a-coefficients are regression coefficient estimates. The a-subscripts have the following broiler price designations: UF for U.S. farm price, UR for U.S. retail price, CF for Canadian farm price, and CR for Canadian retail price. TRD is a time trend. The a-coefficient with an upper case "T" subscript is the coefficient estimate on the time trend. The a-coefficients with a zero denote the intercept estimates. The A_t, B_t, C_t, and D_t denote the error terms or innovations of the USFP, USRP, CFP, and CRP equations, respectively. Eleven indicator variables account for seasonal effects. Data are in natural logarithms, and k refers to the number of lags.

Statistics Canada provided the Canadian farm price (CFP) of broiler chickens and the Canadian retail price index (CRP) for broilers. The U.S. Bureau of Labor Statistics provided the U.S. prices: producer price index ("farm products" index group) for broilers and fryers as the USFP and the consumer price index ("all-urban consumers" index group) for fresh whole chicken, as the USRP. All prices were converted to deflated Canadian dollars. Data were modeled in natural logarithms, such that shocks to and impulse responses in the logged prices represent proportional changes in the nonlogged prices. When multiplied by 100, the impulse responses reflect percentage changes in the nonlogged prices.

Data for all four prices were obtained from January 1966 (1966:1). Twelve observations were removed from each period's onset for use in the Tiao and Box likelihood ratio test procedure for lag selection (*23*). These results (not reported here) suggest, at Lutkepohl's suggested significance level of 1 percent, six lags for the early model and nine lags for the recent model.

For both models, each equation's Ljung-Box Q statistic, distributed as a chi-square variable, tested the null hypothesis that the equation was properly specified to render white noise residuals (*16*, p. 99). One rejects the null hypothesis when an equation's Q-value exceeds the critical value. Assuming a 1-percent significance level, the critical chi-square value is 58.6 with 36 degrees of freedom for the early model and 47 with 27 degrees of freedom for the recent model. Evidence was insufficient to reject the null hypothesis of model adequacy for all eight equations in both models. The early model's Q-values ranged from 27.5 to 34.5, while those of the recent model ranged from 15.5 to 23.6.

Dickey-Fuller (DF) and augmented Dickey-Fuller (ADF) tests were performed on the residuals of each of the four equations in each model. Dickey and Fuller (*11*, *12*) developed a stationarity test by regressing a variable's (here a VAR equation's residuals') first differences against a one-period lag of the variable's nondifferenced levels and a constant. Engle and Granger (*14*) and Hall (*17*) employed an ADF test. In addition to the DF test's regressors, the ADF test regressors include a number of lagged dependent variables (here, lags of the differenced residuals). Hsiao's (*18*) method of lag selection based on Akaike's final prediction error criterion determined the number of lagged dependent variables in each test. With the DF and ADF tests, the null hypothesis of a nonstationary series is rejected when the t-like value on the nondifferenced lagged regressor is negative and exceeds about 3.5 in absolute value (*11*, *12*, *15*, *17*). For the early model, pseudo-t values ranged from –11.5 to –12.4 for the DF tests, and from –7.5 to –8.3 for the ADF tests. For the recent model, the pseudo-t values ranged from –8.4 to –12.01 for the DF tests, and from –5.9 to –6.9 for the ADF tests. So evidence was sufficient in all cases to reject the null hypothesis of nonstationary residuals, and this suggests stationarity of both modeled VAR's.

The analytical procedure involved several phases. First, the VAR's in equations 1 through 4 were estimated for the early and recent periods with ordinary least squares, a procedure that Bessler (*5*, *6*) noted as appropriate.

Second, two experiments were performed on each model. Each model was shocked with a one-time increase in U.S. farm price, and the CFP and CRP responses were observed. Then, each model was shocked with a one-time rise in U.S. retail broiler price, and the responses in the two Canadian broiler prices were examined. Kloek and Van Dijk's Monte Carlo methods were employed and provided a t-value to test the null hypothesis that each impulse is zero (see *1*).

Third, decompositions of forecast error variance (FEV) were calculated, analyzed, and compared for each model to determine how the four prices were interrelated in each period. This study follows Sims (*21*) and employs Chow's method to test for coefficient constancy ("structural change") on each of the model's equations. The Chow test results suggest whether the modeled prices have experienced statistically signifi-

cant change between the two periods, and show where in the VAR's such change has occurred (*22*).

Dynamic information on Canadian broiler price responses from U.S. price shocks for the recent and early models include reaction times, directions and patterns, and durations of statistically nonzero impulses of Canadian broiler prices. Also, results permitted a comparison of Canadian impulse responses across Canada's farm and retail sectors, as well as how such response patterns today resemble, or differ from, those experienced before the 1979 implementation of national broiler supply measures.[2] We learned how the interrelationships among American and Canadian broiler prices have changed since the 1979 Canadian program was implemented.

Influences of U.S. Broiler Price Shocks on Canadian Broiler Prices

The impulse response function simulates, over time, the effect of a one-time shock in one of a VAR's series on itself and on other series in the system (*5*). Each model was shocked with a one-time increase in USFP and then in USRP. Canadian impulse responses in farm and retail broiler prices were then comparatively analyzed across the Canadian farm and retail sectors, and then across time (early, recent periods).

Following standard procedure, a shock equaled the absolute value of the standard error of the shock variable's historical innovation, hereafter denoted the variable's standard error (*5*, *25*). These shocks constitute 7.5-percent and 4.2-percent increases in the early period's American farm and retail broiler prices, respectively, and 5.8 percent and 2.3 percent for the recent period's USFP and USRP, respectively.

A Choleski decomposition was imposed on each VAR to orthogonalize the current innovation matrix, such that the variance/covariance matrix of each model's innovations is identity. The series were ordered as USFP to USRP to CFP to CRP. For both countries, this paper follows previous research and places farm price ahead of retail price because this is the observed chronological ordering of such pricing points in the food and fiber chain (*3*, *4*). Such an ordering is further in line with such standard agricultural price texts as Tomek and Robinson (*24*). U.S. broiler prices were placed ahead of the two Canadian prices because of the Canadians' past perceptions that influences ran from U.S. to Canadian broiler prices—perceptions that partly led to the Canadian broiler supply measures.

Figure 1 shows the impulse *responses* (not levels) in Canadian broiler price to U.S. broiler price shocks for the early model. Figure 2 shows Canadian broiler price responses to American broiler price increases for the recent period after the implementation of the national supply management program. Circled impulses denote Canadian broiler price impulses that are statistically different from zero at the 5-percent significance level. We emphasize the statistically nonzero impulses.

Panels 1a and 2a provide Canadian farm price responses to a rise in U.S. farm price for the early and recent models, respectively. Before national broiler supply management, a rise in U.S. farm price was followed by immediate and statistically significant increases that peaked in month 4, and that endured for 6 months. Today, CFP responds to a USFP increase in a delayed manner, and endures for just 1 month.

Panels 1b and 2b provide Canadian retail price responses from an American farm price increase. Before national supply management, Canadian retail responses to a USFP shock were immediate, accelerated in power through the month-4 peak, and lasted with significance for 10 months. Today, USFP shocks seem to have a far less enduring impact on CRP, which now responds for only 6 months, during which most (five) impulses are significant.

Panels 1c and 2c provide Canadian farm price impulses from a USRP increase for the early and recent models, respectively. Prior to national supply management, CFP responses were immediate, accelerated in strength through a month-6 peak, and endured for 8 months. Today, the USRP/CFP link has been virtually wiped out, with evidence insufficient to suggest that any of panel 2c's CFP-responses were nonzero.

Panels 1d and 2d show Canadian retail price responses triggered by a rise in American retail price for both models. Before the 1979 national supply management program, CRP rose in a largely significant pattern for 9 months. Since 1979, CRP responses are almost all statistically zero and virtually without direction.

The four comparisons in the two figures indicate the

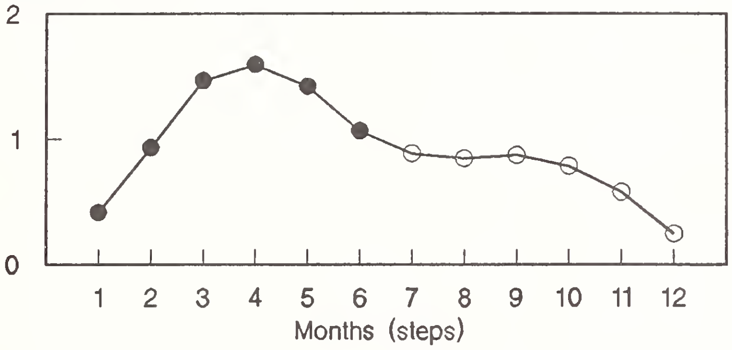
[2] We would have preferred to analyze the dynamic consequences on U.S/Canadian broiler price transmissions of both Canada's national and (assorted) provincial supply programs. Three models would have been required: (a) one estimated over a period before the provincial and national measures, (b) one estimated over a period after implementation of the provincial measures but before the national measures, and (c) one estimated over a period following implementation of both Canada's provincial and national measures. Comparison of models (a) and (b) would investigate the dynamic impacts on U.S./Canadian broiler price transmissions of provincial measures, and comparing models (b) and (c) would investigate the influence of the Canadian NSM program. Comparing models (a) and (c) would furnish the dynamic impacts of both the Canadian provincial and national measures. Data were not historically plentiful enough to estimate model (a) with adequate degrees of freedom, precluding the comparisons of models (a) and (b) and models (a) and (c). So, we concentrated on estimating early VAR model (b) over the 1967:1-78:12 period and the recent model (c) over the 1980:1-87:12 period. These two models offered a comparison of the U.S./Canadian broiler price transmissions before and after the Canadian NSM program, whereby both periods fell within the regime after implementation of the provincial programs. We cut the recent model's estimation off at 1987:12 to prevent possible preliminary influences of what was thought by many in 1988 to be an imminent FTA (*7*).

Figure 1

Canadian Broiler Price Impulses, PD 1

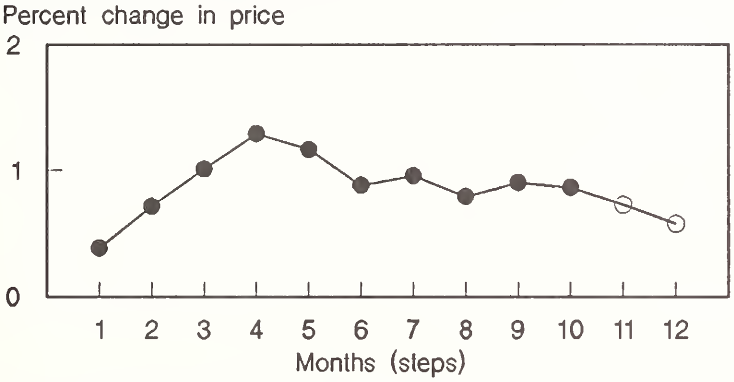
Panel 1a: Canadian farm broiler price impulses from a shock in U.S. farm price: Early period

Percent change in price



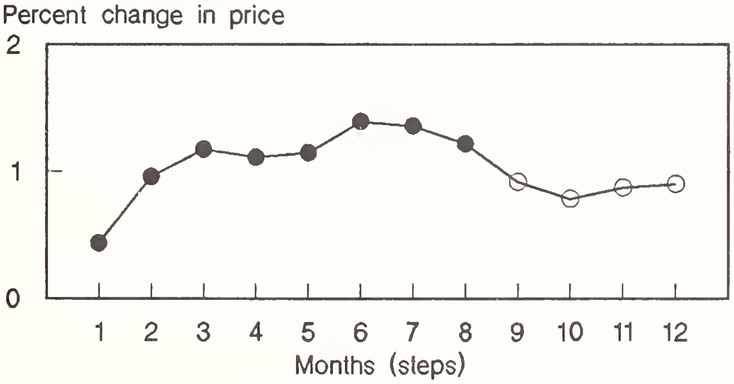
Panel 1b: Canadian retail broiler price impulses from a shock in U.S. farm price: Early period

Percent change in price



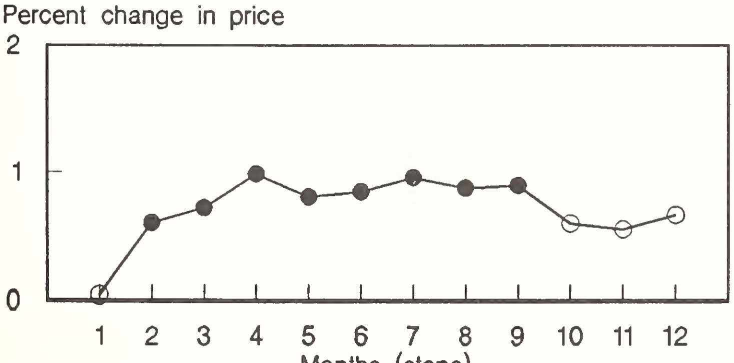
Panel 1c: Canadian farm broiler price impulses from a shock in U.S. retail price: Early period

Percent change in price



Panel 1d: Canadian retail broiler price impulses from a shock in U.S. retail price: Early period

Percent change in price



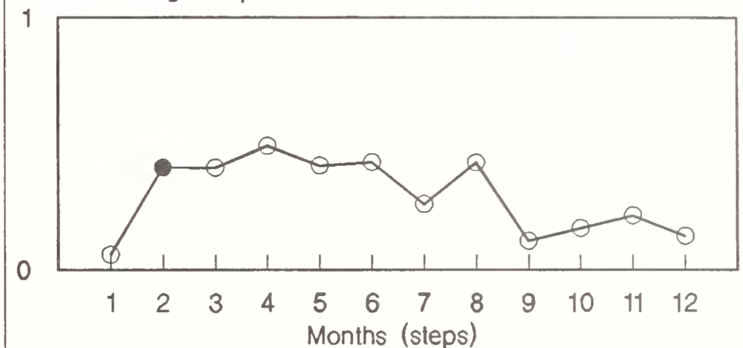
Highlighted (solid) impulses are statistically nonzero at the 5-percent siginificance level.

Figure 2

Canadian Broiler Price Impulses, PD 2

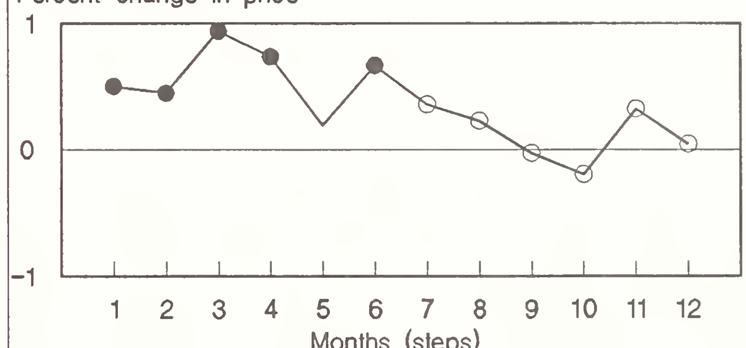
Panel 2a: Canadian farm broiler price impulses from a shock in U.S. farm price: Recent period

Percent change in price



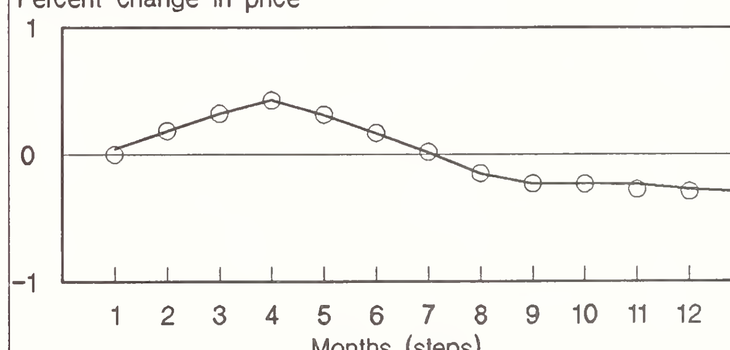
Panel 2b: Canadian retail broiler price impulses from a shock in U.S. farm price: Recent period

Percent change in price



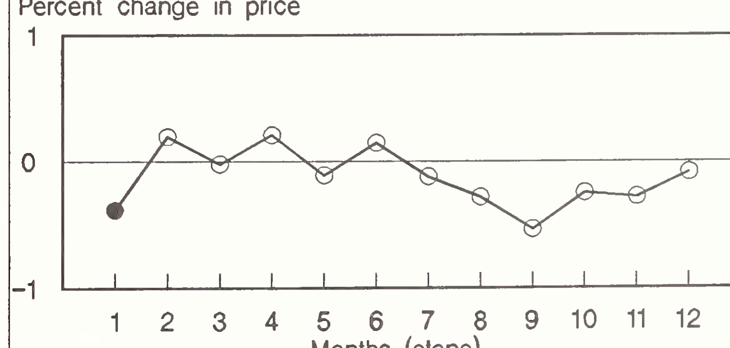
Panel 2c: Canadian farm broiler price impulses from a shock in U.S. retail price: Recent period

Percent change in price



Panel 2d: Canadian retail broiler price impulses from a shock in U.S. retail price: Recent period

Percent change in price



Highlighted (solid) impulses are statistically nonzero at the 5-percent significance level.

successes and failures of Canada's NSM in insulating Canadian broiler prices from U.S. broiler price movements. The figures furnish early/recent model comparisons of the dynamic price transmission for the following four U.S./Canadian broiler price linkages: USFP/CFP in the a-panels; USFP/CRP in the b-panels; USRP/CFP in the c-panels; and USRP/CRP in the d-panels.

The Canadian NSM program was largely successful in blocking these four price linkages. The early-model panels in figure 1 clearly indicate that the four linkages were conduits of cross-border price transmissions of noticeable strengths and durations before the 1979 implementation of Canada's NSM program. Yet figure 2's panels show that after 1979, three of the four linkages were blocked (or nearly so): USFP/CFP, USRP/CFP, and USRP/CRP. And further, the one linkage (USFP/CRP) that managed to endure after 1979 was noticeably weakened.

On the other hand, while largely successful, the Canadian NSM program has not completely blocked these four price linkages and their U.S./Canadian broiler price transmissions. Panels 1b and 2b suggest cross-border price impulses at the Canadian retail level. The data-oriented and nonstructural methods used here have imposed a minimum of theoretical restrictions on the data to discern these pre- and post-1979 price transmission dynamics. As Bessler (*5*) has noted, the methods are designed to indicate what pre-1979 dynamics existed and what post-1979 dynamics still exist, but say little concerning the cause of the dynamics in each of these two periods. Our methods cannot reveal why, for example, the remaining cross-border broiler price transmissions are focused primarily on Canadian retail prices. Such issues are for more theoretically based and market-oriented models and analyses. Bessler (*5*) noted, however, that dynamic results such as ours set the stage for, and constitute the first stage of, such theoretical and market-oriented inquiry.

Decompositions of Forecast Error Variance

Analysis of decompositions of forecast error variance (FEV) identifies the interrelationships among a modeled system's time series (*21*). Error decompositions attribute within-sample error variance to alternative series and thus give a measure useful in applied work (*5*). FEV decompositions for k-step ahead forecasts were calculated for early and recent models (table 1). (Note that FEV decompositions for USFP and USRP were not of direct relevance to this inquiry and were eliminated to conserve space.) A variable is considered largely exogenous/endogenous when large/small portions of its FEV are attributed to own-variation (*5*). In the recent period since implementation of national broiler supply management, Canadian farm broiler price is largely exogenous at most reported horizons (30 months or less) because more than half of the FEV is self-explained. CRP contributes substantially to CFP's FEV at most horizons.

Since the supply management program began, both U.S. (farm and retail) prices have contributed less toward the explanation of the CFP's FEV than previously at most horizons. This coincides with the dampened Canadian price responses elicited by American broiler price shocks since the early period.

Since 1979, Canadian retail price has been highly exogenous, with more than half of its FEV self-attributed at most reported horizons. Canadian farm price is the second largest contributor to CRP's FEV at all reported horizons.

Canadian retail price relationships to other modeled broiler prices have changed in several ways since 1979. CRP has become more exogenous. CFP contributes less toward the explanation of CRP's FEV than formerly at most horizons. Also, USRP now contributes less toward explaining the CRP's FEV than formerly at all horizons. This lessened USRP contribution to Canadian retail price's uncertainty reinforces the lessened CRP impulse responses elicited by American price shocks.

Formal Evidence of Structural Change

"Structural change" denotes a situation when statistical evidence suggests (here, at the 5-percent significance level) that regression coefficients have changed between the early and recent periods. Following Sims (*21*), this study used the Chow test on each of the four price relations to test whether coefficients have changed since the period before January 1979. Due to space considerations, this study does not summarize the actual test. We refer the reader to Shrader, Bessler, and Preston for specifics on this test (*22*).

One rejects the null hypothesis that an equation's coefficients are constant over the two periods when the full vs. reduced F-value exceeds the tabular value (1.44 with 37, 166 degrees of freedom). Of the four F-tests, evidence was insufficient to suggest structural change in the USFP, USRP, and CFP equations. With a 1.54 F-value, evidence was sufficient to suggest structural change in the CRP or Canadian retail broiler price equation. Perhaps this evidence of change arises, in part, from the enhanced degree of CRP exogeneity in the recent period (table 1).

Findings and Conclusions

Evidence suggests that today's U.S. broiler price movements are followed by smaller and less enduring responses in Canadian broiler prices than during the period preceding Canada's national broiler supply

Table 1—Proportions of forecast error variance of Canadian broiler prices, k months ahead, allocated to innovations in U.S. and Canadian broiler prices

Price and k (months ahead)	Standard error	U.S. farm price	U.S. retail price	Canadian farm price	Canadian retail price
			Percent		
Model for early period: 1967:1—1978:12					
Canadian farm price:					
1	0.03012	11.48	12.23	76.28	0
6	.06636	21.93	20.02	55.75	2.31
12	.08867	15.44	17.88	62.99	3.68
18	.09971	13.13	17.19	66.56	3.12
24	.10677	12.54	20.04	64.69	2.73
30	.11122	11.65	24.00	61.75	2.60
36	.11304	11.28	25.80	60.33	2.59
47	.11347	11.34	26.07	59.97	2.62
48	.11350	11.35	26.05	59.97	2.62
Canadian retail price:					
1	.02414	11.34	6.24	11.77	70.66
6	.05221	23.45	15.19	24.11	37.25
12	.07006	19.42	14.56	40.57	25.45
18	.07959	15.41	13.45	51.25	19.90
24	.08570	14.70	15.00	53.13	17.17
30	.08976	13.70	19.08	51.49	15.72
36	.09195	13.07	21.83	49.99	15.11
47	.09257	12.99	22.54	49.52	14.95
48	.09259	13.01	22.53	49.51	14.95
Model for recent period: 1980:1—1987:12					
Candian farm price:					
1	.01794	5.20	1.13	93.62	.06
6	.03354	8.81	3.99	86.80	.40
12	.03720	7.93	5.69	84.05	2.33
18	.04130	10.67	6.44	68.89	14.00
24	.04706	14.29	5.24	55.39	25.07
30	.04843	16.37	5.51	52.57	25.55
36	.05440	13.05	7.75	43.69	35.51
47	.06442	9.51	11.28	33.51	45.69
48	.06446	9.50	11.35	33.47	45.67
Canadian retail price:					
1	.02222	9.16	3.78	16.36	70.69
6	.03443	21.02	2.36	28.10	48.52
12	.03936	17.45	5.52	28.93	48.10
18	.04302	15.73	5.30	26.46	52.51
24	.04992	13.31	5.96	21.70	59.03
30	.05130	13.30	6.27	20.72	59.71
36	.05330	12.41	6.59	20.04	60.96
47	.05805	10.59	8.90	17.65	62.85
48	.05807	10.59	8.94	17.64	62.82

management program. Since the early period, the Canadian price responses to a USFP shock are more delayed and far less enduring (1 month instead of 6) at the farm level, and endure only 6 months (instead of 10) at the retail level. In a statistical sense, the Canadian farm and retail broiler price responses to USRP shocks appear to have been eliminated since the early period.

Generally, results of the impulse responses, FEV decompositions, and Chow tests all point to change at Canadian retail price level. Results suggest that: (1) American broiler price fluctuations influence the recent model's CRP less than the early model's CRP; (2) the FEV decompositions imply that the recent model CRP is more exogenous and less dependent on the Canadian farm price than in the early model; and (3) structural change has occurred at the CRP level. These results fail to contradict the evidence uncovered by Coffin, Romain, and Douglas (*10*) that the Canadian food retail industry is becoming more concentrated in a few, large firms, with more market power at both the provincial and national levels. But, we conjecture that the Canadian food retail industry may have been changing and becoming less competitive in nature, such that CRP is more dependent on its own past levels than on other related prices in the neoclassical competitive production model. But, this is only conjecture,

as our nonstructural statistical methods do not offer insight concerning such explanations.

The Canadian NSM program has been largely successful in blocking the price transmissions through the four examined U.S./Canadian broiler price linkages. Since the program's 1979 implementation, three have been blocked or nearly blocked. The one remaining linkage conducts cross-border price transmissions that are weaker and only about half as enduring as the same transmissions before the Canadian NSM program's implementation.

These results are useful to policy analysts charged with liberalizing the U.S./Canadian agricultural trade, or to other analysts interested in adapting policies similar to Canada's NSM program. Canadians must know the cross-market consequences on their broiler prices of a grain-related liberalization which would influence the price of U.S. feed and, in turn, of U.S. broilers. Canadians and Americans should know the degrees to which existing broiler and nonbroiler agricultural programs directly or indirectly impede Canadian/U.S. trade in broiler products.

Another result is a methodological one. We have shown that useful policy analysis is possible using the data-oriented time series techniques of vector autoregression. Policy analysis that involves such dynamic aspects of price transmissions as the following can be successfully addressed using these techniques: price response reaction times, response directions and patterns, and response durations. As Bessler (*5*, *6*) notes, these dynamics are often not adequately addressed by more conventional structural econometric models, or by the static theory underlying such models. These structural models use static theory, modeling well what happens at pre- and post-shock equilibria. We, however, have modeled what dynamically happens to selected variables between the pre- and post-shock equilibria. In so doing, we have shown that the nontheoretical and nonstructural VAR methods can effectively analyze policies that involve the dynamic characteristics of the examined price transmissions.

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Farmer Response to Changes in Climate: The Case of Corn Production

LeRoy Hansen

Abstract. *A test of whether minor production adaptations to climate significantly affect corn yields is the focus of this article. Cross-sectional, field-level corn data are used to analyze production across various climates. A 6.5°F change in temperature, when both adaptations to climate and the direct effect of weather are included, raised yields by 43.8 percent in areas with average July temperatures of 67°F and reduced yields by 69.6 percent in areas with average July temperatures of 76.5°F.*

Keywords. *Plant growth models, corn production, climate changes, greenhouse effect.*

Some scientists expect a rise in global temperatures, due to an increased accumulation of carbon dioxide (CO_2), methane, and other greenhouse-effect gases in the atmosphere (*7*).[1] Some researchers estimate that the climatic effects of a doubling of greenhouse gases are likely to appear within 50 to 100 years (*30*). Global climatic change can lead to changes in agricultural production in the United States and the rest of the world, either directly through effects on crop yields, or indirectly as prices of agricultural commodities balance demands with new crop yield potentials.

Understanding the effects of climate changes on agriculture is necessary for the development of technologies to mitigate future problems, and for indicating potential costs associated with a rise in the levels of greenhouse gases. Uncertainties remain, however, concerning the effects of climate change.

First, there is considerable uncertainty about the rate of accumulation of the most significant greenhouse-effect gas, CO_2 (*18*).

Second, changes in weather patterns are uncertain. Simulations of weather patterns resulting from greenhouse gas accumulation are estimated using three-dimensional mathematical models called Global Circulation Models (GCM's). Different GCM's, however, provide different climate projections under the same scenario of greenhouse gas accumulation. Furthermore, GCM's provide only projections of changes in average seasonal temperature and precipitation and do not include important details on changes in weather variability, extremes of temperature and precipitation, or the amount of cloud cover.

Third, researchers are concerned about the accuracy of the estimated direct effects of climate and CO_2 fertilization on crop yields. Direct effects (for example, effects before consideration of price changes) have been estimated using computer simulations of crop growth, or crop growth models (*5, 6, 16, 18, 21, 22, 23, 27, 30*). Crop growth models simulate day-by-day crop growth subject to the projected climate (such as precipitation, temperature, and cloud cover), the level of CO_2, the application of irrigation water and fertilizers, and the soil type. Analyses of the indirect effects (for example, yields after adjustments to subsequent prices) of climate change result from the direct effects and the subsequent changes in agricultural input and output prices and production levels, given projected output demands (*9*). The indirect effects must account for elasticities of substitution and economies of scale.

Crop growth models may not fully reflect the range of farmers' responses to climate change. Most crop growth models allow for farmers' adjustments in nitrogen use and irrigation levels and sometimes other major inputs to a new climate. Unless crop growth models include all adjustments to climate (or expected weather) that significantly affect yield, their estimated effects of climate change will be biased.

This study tests whether there are significant yield effects of production adaptations to climate that are not included in crop growth models. The null hypothesis states: Adjustments in input use and management practices to climate, which are not included in plant growth models, have no effect on yield. This hypothesis is tested using regression techniques on field-level data from the 10 major corn-producing States. Cross-sectional data provide a view of production across areas of different climatic conditions, where production practices embody local technologies to maximize profits for the region's climate.

Estimation results indicate a rejection of the null hypothesis. Thus, minor production adaptations to climate appear to have a significant effect on yield. Crop growth models may be producing biased estimates, at least in corn production. The results presented here do not specify the adaptations that could improve crop growth models. However, the significance of the results suggests that efforts to detail adaptations to climate may be fruitful.

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[1]Italicized numbers in parentheses cite sources listed in the References section at the end of this article.

Farm Production Adaptations to Climate

An approach to estimating the yield effect of farm production adaptations to climate under a fixed set of input and output prices follows directly from a characterization of the profit-maximizing farmer. For each growing season, in a given field, the farmer determines optimal input application rates based on the marginal physical products, prices of the inputs, and the expected output price. That is to say, the farmer attempts to maximize:

$$\Pi = P^*Y - XC, \tag{1}$$

where:

Π = expected economic profit (per acre),
P = expected output (corn) price,
Y = output (yield) and Y = f(X) where f(X) is assumed to be continuously differentiable across all X,
X = a vector of the factors of production, and
C = a vector of input prices associated with X.

The first n elements of X, $x_1 \ldots x_n$ represent factors of production under the control of the farmer, such as chemical nitrogen, seed choice, crop rotation pattern, and tillage practice. The remaining w elements of X, $x_{n+1} \ldots x_{n+w}$ are the environmental inputs or factors that the farmer cannot adjust directly, such as the characteristics of the soil, weather, and climate.

Weather is actual (observed) temperature and precipitation and thus directly affects yields. Webster's New World Dictionary defines climate as "the prevailing or average weather conditions of a place as determined by the temperature and meteorological changes over a period of years." Climate, therefore, indicates what type of weather to expect.

Equation 1 is maximized when:

$$\partial Y/\partial x_i = c_i/P, \tag{2}$$

for all $i \leq n$, subject to the farmer's knowledge or expectation of $x_{n+1} \ldots x_w$, where c_i represents the price of the i^{th} factor.

The yield effect of a change in the environmental factor x_j can be expressed as:

$$\partial Y/\partial x_j = \partial f(X)/\partial x_j + \sum_{i=1}^{n} (\partial f(X)/\partial x_i * \partial x_i/\partial x_j), \tag{3}$$

where $n < j \leq n + w$. The first term on the right-hand-side of equation 3 represents the direct effect on yield of the change in the environmental input x_j. The second right-hand-side term represents the change in yield as input use is adjusted for the change in the environmental input. When x_j represents July weather, the second right-hand-side term will likely equal 0 since there are few production adjustments available to the farmer in July.[2] When the environmental input, x_j, represents expected weather or climate, the first right-hand-side term will equal 0. Instead, the adjustments in input use or production technologies to expected weather will result in a nonzero value to the second right-hand-side term. Assuming that the yield effects of adjustments in input use and production technologies ascribed to climate can be described by some function G(C), where C represents the set of climate variables from the vector X:

$$\partial G/\partial x_j = \sum_{i=1}^{n} (\partial f(X)/\partial x_i * \partial x_i/\partial x_j). \tag{4}$$

When $[\partial f(X)/\partial x_i * \partial x_i/\partial x_j] = 0$ for any i, then $\partial G/\partial x_j = 0$. A test of significant adjustments in input use and management practices relating to climate becomes a test of the significance of climate as a determinant of yield. That is, the proposed hypothesis will be rejected if any of the n input adjustment terms for climate are significantly different from zero and those effects are characterized by G(C).

Yield Responses to Weather and Input Use

The relationship between yield and the inputs supplied by man and nature has been examined by agronomists, economists, soil scientists, and others. One significant problem in estimating yield functions is determining the correct functional form.

Commonly estimated yield functions are linear across most inputs with quadratic or logarithmic measures of particular inputs with nonconstant marginal physical products (*3*, *7*, *11*, *14*, *19*, *26*, *28*). Such a generalized model is applied here.[3] Thus, yield (Y) at the j^{th} site (observation) is written as:

$$\begin{aligned} Y_j = {} & \alpha_0 + \alpha_1 LOWTIL_j + \alpha_2 NOTILL_j + \alpha_3 IRRIG_j \\ & + \alpha_4 CORN_j + \alpha_5 CORNCORN_j + \alpha_6 ERODE_j \\ & + \alpha_7 NITRO_j + \alpha_8 NITROSQ_j + \alpha_9 LNSEED_j \\ & + \alpha_{10} PLDATE_j + \alpha_{11} SLPLGTH_j + \alpha_{12} TFACT_j \\ & + \alpha_{13} KFACT_j + \alpha_{14} PREJUL_j \end{aligned} \tag{5}$$

[2]Irrigation is a production adjustment that farmers may be able to make during the July portion of the growing season. This production adjustment was tested by including irrigation and weather interaction terms and was found not significant.

[3]Also tested was a log-log yield function (or Cobb Douglas) of the form:

$$Yield_j = \alpha_0 * e^{\sum_{i=1}^{m} \alpha_i X_{ij}} * \prod_{i=m}^{n} x_{ij}^{\alpha_i} * \delta_j,$$

where the variables x_1 through x_m represent the independent variables that are zero-one dummies, x_{m+1} through x_n are the independent variables having continuous values, the α's are estimated as regression coefficients, and δ is an error term assumed to be distributed so that $\ln(\delta) \approx N(0,\sigma^2)$. This model performed poorly, partially due to its inability to adjust for changes in the sign of the output elasticity of some variables.

$$+ \alpha_{15}PREJULSQ_j + \alpha_{16}TMPJUL_j$$
$$+ \alpha_{17}TMPJULSQ_j + \alpha_{18}PAVGJUL_j$$
$$+ \alpha_{19}PAVGJULSQ_j + \alpha_{20}TAVGJUL_j$$
$$+ \alpha_{21}TAVGJULSQ_j + \alpha_{22}TJULINT_j$$
$$+ \alpha_{23}PJULINT_j + \alpha_{24}TMPPRESQ_j$$
$$+ \alpha_{25}PRETMPSQ_j + \epsilon_j,$$

where the α_0 is the intercept, the remaining α's are the coefficients on the independent variables, and ϵ_j is the error term. Six of the variables are zero-one dummy variables (see table 1):

LOWTIL indicates a 30-percent residue cover remaining after tillage;

NOTILL indicates no tillage between harvest of the previous crop and planting:

IRRIG indicates the field was irrigated;

CORN indicates corn was grown on the field in the previous year;

CORNCORN indicates corn was grown on the field in the previous 2 years;

ERODE indicates that more than half of the agricultural land in the county was classified as erodible.

NITRO and NITROSQ represent the pounds per acre of nitrogen applied and pounds squared, respectively. LNSEED is the natural log of the kernels/acre seeding rate. The use of a second-degree term to account for the diminishing marginal product of nitrogen outperformed the log of nitrogen, but the opposite occurred with the seeding rate. PLDATE is the planting date. SLPLGTH is the slope-length (in feet), TFACT is the soil's erosion tolerance factor, and KFACT is the soil's erodibility factor. Both TFACT and KFACT were derived for use in the Universal Soil Loss Equation.

The weather and climate variables include: actual July precipitation, PREJUL; PREJUL squared, PREJULSQ; average July temperature, TMPJUL; TMPJUL squared, TMPJULSQ; the 30-year average of July precipitation as one characterization of climate, PAVGJUL; PAVGJUL squared, PAVGJULSQ; the 30-year average of July temperatures, TAVGJUL; and TAVGJUL squared, TAVGJULSQ and interactions among these variables, that include: TJULINT (=TMPJUL * TAVGJUL), PJULINT (=PREJUL * PAVGJUL), TMPPRESQ (=TMPJUL * PREJULSQ), and PRETMPSQ (=PREJUL * TMPJULSQ).

While the expectation of significant interactions between temperature and precipitation is self-evident, the interactions between climate and weather were included to account for changes in the marginal impacts of weather with respect to climate. Growing conditions in July are strategic because July is the most common period for corn to pollinate.

To ensure that adaptations to climate in one area were applicable to another, location-specific factors were included in the analysis. ERODE, IRRIG, CORN, CORNCORN, SLPLGTH, PLDATE, TFACT, and KFACT were significant. Also included, but dropped for lack of significance, were variables indicating soil permeability, soil water-holding capacity, growing season cultivations for weed control, land of capability class 1 or 2, previous crop (wheat, soybeans, or alfalfa), the harvest date, and herbicide and insecticide use. If any location-specific factors remained, they were assumed to be orthogonal to the climate variables.

Other climate and weather variables were dropped for lack of significance such as June precipitation as both climate and weather variables, August temperatures as both climate and weather variables, interactive precipitation and temperature variables for climate, and first-degree interactive terms for weather.

Data

Field-level observations on corn yields and the inputs used by farmers came from the 1988 and 1989 Objective Yield Surveys (OYS), which is a random sample of acres in corn production. There are 3,057 of these field-level observations spread across the 10 major corn-producing States (Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Nebraska, Ohio, South Dakota, and Wisconsin). Farmers furnished information on irrigation, seeding rate and timing, crop rotation, nitrogen use, weed and pest control, tillage practices, harvest date, and the consequential yield on the sample field. Thus, variables representing this information come directly from the OYS. The level of remaining crop residue used to determine LOWTIL was derived from OYS tillage and previous crop information (*2*).

The OYS identifies the county where each observation is located. The county identification identifies the soil, weather, and climatic conditions associated with each observation.

The National Oceanic and Atmospheric Administration (NOAA) supplied monthly weather data from data bases. The 3,057 observations spanned 83 different multi-county weather districts. Climate data were derived by averaging 30 years of monthly weather conditions. Climate variability across the sample ranged from 67°F to 80°F in average July temperatures and 1.9-4.5 inches in average July precipitation.

The 1985 National Resource Inventory (NRI) and the Soils-5 survey gave soil information. Characteristics of the soil for each observation were determined by their county averages. Only NRI sample points on cropland were used. Thus, the water-holding capacity, permeability, slope length, TFACT, and KFACT for each observation came from the average across the NRI cropland sample points within the appropriate county.

Estimation

A tobit model was used to estimate equation 5 because of a cluster of zero-yield observations (*29*). As first shown by Tobin, analyses of data where the dependent variable is censored must recognize the resulting error distribution and the factors underlying its truncated and continuous values.

A tobit estimation procedure is applicable when the censoring of the dependent variable is driven by the same factors that determine the variable's magnitude. There is no reason to suggest that this condition does not hold in analyzing corn yields. Farmers do not harvest when yields are very low because harvesting costs and any forage value of the corn are not covered. This nonzero censoring problem is corrected by subtracting 9 bushels per acre, the lowest nonzero reported yield, from all nonzero values of Y (*4*).

Heteroscedasticity occurs when the variance is correlated with some set of variables, Z. Problems of heteroscedasticity in tobit models can be overcome by making reasonable assumptions about the nature or source of the heteroscedasticity (for example, the elements of Z), testing the assumptions, and adjusting the estimation of the model accordingly (*12*). The correcting for heteroscedasticity is especially important in tobit models because the presence of uncorrected heteroscedasticity can result in estimates that are neither efficient nor consistent (*13*).

Heteroscedasticity is tested and adjusted for following a generalized specification of the variance suggested by Rutemiller and Bowers:

$$\sigma_k^2 = (\tau + \delta Z_k)^2, \qquad (6)$$

where Z is a vector of variables hypothesized to affect the variance, δ is a vector of coefficients, τ is the homoscedastic component of the variance (for example, when $\delta=0$ then $\tau^2=\sigma^2$), and the k subscript denotes subpopulation (or observation) k.

Heteroscedasticity is tested as a function of climatic conditions, the observation year, farmer-applied inputs, and location-specific factors. Climate is hypothesized to affect variance because the sensitivity of corn yields to deviations in climatic conditions is expected to be most significant in the most productive climates. Observation year serves to account for any differing in variance between years. Farmer-applied inputs and location-specific parameters are included, given their possible effect on variance.[3]

Results

Equation 5 was estimated subject to equation 6, where variables with t-statistics of less than 1 were dropped from the model (table 1). Despite applying the conservative critical t-value of 1, most of the remaining variables are significant at the 95-percent level. The R-square, corrected for degrees of freedom, indicates that the estimated model explains 77 percent of the variation in yield, which is high for field-level data.

Signs and magnitudes of the estimated tobit coefficients were as expected (table 1). Because the focus of this article is on the estimated dependency of yield on climate and weather, the implications of the other coefficients are not discussed. The listing and discussion of the results of testing and correcting for heteroscedasticity are in the appendix and appendix table 1.

Hypothesis Test Results

The indirect effects of climate on yield were significant at the 95-percent level for five of the six climate variables (PAVGJUL, PAVGJULSQ, TAVGJULSQ, TJULINT, and PJULINT), indicating a strong rejection of the null hypothesis (table 1). Acceptance of the alternative hypothesis indicates that the effects of minor production adjustments to marginal changes in climate are significant enough to warrant their inclusion in analyses of yields under changing climatic conditions. The direct effects of the weather (PREJUL, PREJULSQ, TMPJUL, TMPJULSQ, TJULINT, PJULINT, PRETMPSQ, and TMPPRESQ) on yield are also significant.

The production adjustments to changes in climate do not include the effect of changes in the planting date, irrigation, tillage practices, and nitrogen use. These variables are included separately in the analysis, and their effect is often accounted for in plant growth models. The effects of these variables are significant and have the expected signs (table 1).

Implications of the Weather and Climate Coefficients

Acceptance of the alternative hypothesis suggests that variations in weather can affect yields more than variations in climate. The greater magnitude of the second derivative of actual temperature relative to climatic temperature indicates that the yields are more sensitive to variations in weather than variations in climate.

[3]The software that allows a tobit estimation of equation 5, subject to restrictions in equation 6, was written and provided by Daniel Hellerstein, ERS.

Table 1—Model estimation results

Variable	Coefficient	t-statistic
LOWTIL	4.60*	2.56
NOTILL	–5.35*	–2.07
IRRIG	22.4**	6.85
CORN	–4.78*	–2.42
CORNCORN	–2.00	–.85
ERODE	–11.9**	–8.23
NITRO	.120**	4.76
NITROSQ	.000202**	–2.65
LNSEED	72.2**	13.10
PLDATE	.275**	–4.45
SLPLGTH	.0162**	2.66
TFACT	12.8**	6.38
KFACT	64.7**	2.88
PREJUL	103*	2.51
PREJULSQ	–34.4**	–3.09
TMPJUL	106**	2.77
TMPJULSQ	–2.15**	–4.00
PAVGJUL	66.2**	3.05
PAVGJULSQ	–9.74**	–3.32
TAVGJUL	58.8	1.89
TAVGJULSQ	–1.80**	–5.51
TJULINT	2.84**	3.75
PJULINT	4.41**	3.60
TMPPRESQ	.424**	2.87
PRETMPSQ	–.0173*	–2.38
Intercept	–6940**	–7.10

Variable	Definition	Source
LOWTIL	> 30 percent of soil covered by previous crop residue	OYS
NOTILL	no tillage performed since previous crop harvest	OYS
IRRIG	dummy = 1 if field was irrigated	OYS
CORN	dummy = 1 if corn grown on field in previous year	OYS
CORNCORN	dummy = 1 if corn grown on field in previous 2 years	OYS
ERODE	dummy = 1 if soil erosion designated as a problem	NRI
NITRO	lbs/acre nitrogen application rate	OYS
NITROSQ	lbs/acre nitrogen application rate squared	OYS
LNSEED	natural log of the seeding rate	OYS
PLDATE	planting date	OYS
SLPLGTH	slope length used in the Universal Soil Loss Equation (USLE)	NRI
TFACT	soil erodibility factor used in the USLE	NRI
KFACT	soil loss tolerance	NRI
PREJUL	actual July precipitation	NOAA
PREJULSQ	actual July precipitation squared	NOAA
TMPJUL	actual July temperature	NOAA
TMPJULSQ	actual July temperature squared	NOAA
PAVGJUL	30-year average of July precipitation	NOAA
PAVGJULSQ	30-year average of July precipitation squared	NOAA
TAVGJUL	30-year average of July temperature	NOAA
TAVGJULSQ	30-year average of July temperature squared	NOAA
TJULINT	= TMPJUL * TAVGJUL	NOAA
PJULINT	= PREJUL * PAVGJUL	NOAA
TMPPRESQ	= TMPJUL * PREJULSQ	NOAA
PRETMPSQ	= PREJUL * TMPJULSQ	NOAA

*Significant at the 95-percent confidence level.
**Significant at the 99-percent confidence level.

The extent to which the production adaptations associated with TAVGJUL mitigate the negative impact of higher temperatures can be seen by examining the effect of weather across different climatic areas. For example, the yield-maximizing July temperature is 70°, 72.2°, 75°, and 77.5°F for regions where July temperatures average (TAVGJUL) 70°, 74°, 78°, and 82°F, respectively, and given PAVGJUL and PREJUL equal 4 inches.[4]

As with temperature, the actual July precipitation (PREJUL) that maximizes yield depends on the minor production adjustments made to the expected level of precipitation (PAVGJUL). The yield-maximizing levels of actual July precipitation are 4.6, 4.2, 3.8, and 3.4 inches, given the production practices associated with July climatic precipitation (PAVGJUL) levels of 4.5, 4, 3, and 2.5 inches, respectively, and average July temperatures of 74°F (TAVGJUL=TMPJUL =74°F). These results indicate that the effect of precipitation on yields can be mitigated by production adjustments. In contrast to temperature, the relative magnitudes of the second-order conditions with respect to the climate and weather precipitation variables appear to indicate that the rate of change in yields due to variations in climatic precipitation is greater than the rate of change in yields due to annual variations in July precipitation. However, the smaller rate of yield response to annual precipitation likely stems from the importance of carryover soil moisture. So, PREJUL does not fully reflect actual variations in moisture availability.

The results also suggest production interrelationships between precipitation and temperature. The climatic precipitation that maximizes yields varies directly with climatic temperature. For example, when TAVGJUL and TMPJUL equal 70°, 74°, and 78°F, yields are maximized at 4.2, 4.5, and 4.9 inches, respectively. PAVGJUL ranges from 1.9 to 4.5 inches across the sample area. Likewise, the climatic temperature that maximizes yields varies directly with climatic precipitation. When July precipitation averages 3 inches, the yield-maximizing climatic temperature is 73.5°F. When July precipitation averages 4.5 inches, the yield-maximizing temperature increases to 74.4°F. TAVGJUL ranges from 67.1°F to 80.0°F across the sample area. (See app. table 1 for means and standard deviations of other variables.)

A partial effect of climate change, which includes only the effects of weather and the minor production adaptations associated with the climate variables, can be obtained from the estimation results. The total effect of climate change on yield must also include the effects of the more major production adjustments to climate that are explicitly included in this and other models. The total effect must also include the associated

[4]Evaluations are made at mean values for the other independent variables.

adjustments in input use and acreage in production to future prices, technology, and plant variety development, and the effects of CO_2 fertilization. The partial effects are made under the assumption that weather patterns in new climate regimes parallel the patterns observed in the cross-section of climates in this analysis.

An Estimation of the Partial Yield Impacts of Climate Change

Farmers' minor production adjustments to climate were found to significantly affect yield. Yet, past studies on climate change and yields have overlooked these minor production adjustments. The magnitude of the yield effects of climate change and the subsequent minor production adjustments are derived from the estimation results.

The effects of weather and minor production adaptations to future climatic conditions are based on projections of the Goddard Institute for Space Science's (GISS) global climate model. The GISS model forecasts rises of approximately 6.5°F in July temperature and 1 inch in July precipitation in the midwestern United States for a doubling of carbon dioxide.

The 6.5°F temperature rise would increase yields by an estimated 44.5 bushels per acre (43.8 percent) for colder regions of the study area but would reduce yields by about 82.3 bushels per acre (69.6 percent) in warmer regions, given only minor production adaptations (table 2). The 82.3-bushels-per-acre yield decrease is a projection made 3°F outside the range of TAVGJUL and so must be viewed with caution. Also, the positive yield effects of the expected increase in precipitation and of the significant production adaptations have been excluded from the reported climatic effects.

The effects of precipitation changes are not as dramatic as those of temperatures. Yield changes range from 14.2 to 1.5 bushels per acre per half-inch change in average July precipitation (table 2). However, PREJUL provides only a partial measure of variation in growing season moisture availability because soil moisture availability is affected by precipitation in previous months, and actual precipitation can fall above average one month and below average the next. Thus, the direct effects of climate change with respect to precipitation are likely underestimated.

Table 2—Yield impacts in different climatic regions[1]

Temperature		Yield change		Precipitation		Yield change	
From	To			From	To		
Degrees F		*Bu/ acre*	*Per- cent*	*--Inches--*		*Bu/ acre*	*Per- cent*
67.0	73.5	44.5	43.8	2.5	3.0	13.9	10.7
70.0	76.5	–6.4	–5.0	3.0	3.5	9.8	8.2
73.5	80.0	–52.4	–38.7	3.5	4.0	5.7	4.4
76.5	83.0	–82.3	–69.6	4.0	4.5	1.5	1.1

[1]Evaluated at mean values of all other independent variables.

Conclusions

The minor production adaptations to climate significantly affect yield. This analysis cannot specify the minor production adaptations and, therefore, cannot offer a specific remedy for improving plant growth models. However, the estimated results offer some insight into the magnitude of the effects of minor production adaptations.

The significance of the yield effects of the minor production adaptations were tested by modeling yield as a function of the more significant production adaptations, local resource characteristics, and minor production adaptations as proxied by climate. Regional soil characteristics and actual weather were included as independent variables to ensure that the climate variables reflected only changes in the less significant farm inputs.

The direct effects on corn yields of a projected 6.5°F change in temperature and 1-inch change in precipitation were estimated for a number of climatic conditions. The estimated changes in yields exclude the effects of adjustments in the major inputs and responses to any subsequent input/output price change. Also excluded are the effects of CO_2 enrichment and improvements in plant varieties and other production technologies. Given these limited conditions, only in the coolest areas were corn yields projected to rise. For the 6.5°F temperature change alone, yields were projected to increase as much as 44.1 bushels per acre (43.8 percent) in areas with average July temperatures of 67°F and fall by 82.3 bushels per acre (69.6 percent) in areas with average July temperatures of 76.5°F.

The importance of production adaptations to climate change depends on farmers' abilities to incorporate them into their operations. Unless farmers perceive a change, there will be no adaptations in production.

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Appendix

The estimation results of the heteroscedastic component of the estimated yield model is listed in appendix table 1. All right-side variables of equation 5 were included as heteroscedastic terms. Variables with t-statistics greater than 1 were dropped from the analysis. Six of the remaining variables, IRRIG, ERODE, SLPLGTH, NITRO, TAVGJUL, and TAVGJULSQ, are significant from zero at the 95th percentile.

The signs on the coefficients indicate greater variance for irrigated corn, for corn-corn rotations, and for soils classified as erodible, although they constitute less than 1 percent of the total variance. Variance also shows a positive correlation with field slope and a negative correlation with the natural log of the seeding rate. The contributions of nitrogen, climatic precipitation, and climatic temperature to variance are minimized at a nitrogen application rate of 196 pounds per acre, when July precipitation averages 10.4 inches and temperature averages 74.9°F. The nitrogen and average July precipitation values exceed most of those in the sample. Thus, variance is a decreasing function across the relevant range of nitrogen use and climatic precipitation. In contrast, the effect of temperature on variance is minimized near the average climatic temperature. Also, when July precipitation averages 4.5 inches, the yield-maximizing temperature equals 74.4°F. So, a significant movement away from the yield-maximizing temperature can also increase the variance of the yield. Neither the climate nor the nitrogen coefficients show as much as a 1-percent contribution to the level of total variance. However, including the heteroscedastic terms does minimize the possibility that the estimates of the coefficients in equation 5 are biased.

Appendix table 1—Estimated coefficients and the standard errors of heteroscedastic variables

Variable	Coefficient	Standard error
IRRIG	4.56	1.80
CORN	2.18	1.23
ERODE	2.26	.977
NITRO	−.0475	.0242
NITROSQ	.000121	.0000895
LNSEED	−3.60	2.39
SLPLGTH	.00845	.00421
PAVGJUL	−4.57	5.49
PAVGJULSQ	.219	.102
TAVGJUL	−33.1	77.5
TAVGJULSQ	.221	.118
Intercept[1]	7,590	2,300

[1] Homoscedastic component of the variance.

Appendix table 2—Means and standard deviations of variables

Variable	Mean	Standard deviation
LOWTIL	0.145	0.352
NOTILL	.0648	.246
IRRIG	.120	.325
CORN	.369	.483
CORNCORN	.238	.426
ERODE	.420	.494
NITRO	129	66.1
NITROSQ	20,900	24,400
LNSEED	10.1	.171
PLDATE	126	11.7
SLPLGTH	222	123
TFACT	4.60	.402
KFACT	.309	.0429
PREJUL	2.34	1.46
PREJULSQ	7.63	9.41
TMPJUL	75.4	1.78
TMJULSQ	5,700	266
PAVGJUL	3.77	.470
PAVGJULSQ	14.4	3.36
TAVGJUL	74.1	2.28
TAVGJULSQ	5,500	337
TJULINT	5,600	284
PJULINT	8.80	5.64
TMPPRESQ	571	701
PRETMPSQ	13,200	8,120

The Beginning and the End of Econometrics?

The History of Econometric Ideas. By Mary S. Morgan. Cambridge, MA: Cambridge Univ. Press, 1990, 296 pages, $44.50.

Reviewed by Clark Edwards

At the turn of the century, economists could be divided into two groups: armchair theorists and brute-force empiricists. The deductive theorists were sometimes introspective and sometimes mathematical. The inductive empiricists relied on history or statistics. Econometrics was seen by its first practitioners as a synthesis of these two apparently disjointed and mismatched approaches to economics. Mary Morgan's fascinating yet easy-to-read history of econometrics during the first half of the 20th century quickly dispels the popular notion that econometrics appeared, almost full-blown, at mid-century. Conflicts arose as theory met data one and two generations earlier, enabling striking changes in approach from 19th-century economics.

Morgan's dramatization of the story of econometrics is in three acts: Act I is devoted to the business cycle; Act II discusses demand analysis; and Act III turns to the evolution of formal models of data-theory relationship since the turn of the century.

Act I opens with Jevons's sunspot theory. Jevons was one of the first to seek systematically a bridge between theory and data, though his link to sunspots was ridiculed by his contemporaries. Jevons distinguished between endogenous and exogenous variables, he relied on evidence of uniformity in statistical data to derive a general theory using inductive reasoning, and his use of "most probable cause" anticipates the idea of "maximum likelihood."

H.H. Moore extended Jevons's theory to the movements of the planet Venus. He abandoned comparative statics in favor of methods explaining the path between two periods. His cyclical theory and statistical methods flouted conventional theory and methods as he learned to use harmonic analysis, correlation, multiple regression, and time-series decomposition. Moore's contemporaries applauded his efforts to bridge the gap between abstract reasoning about what should happen and statistical descriptions of what does happen. At the same time, they criticized his performance. Another example of cosmic theorizing saw Frisch develop a small, "rocking horse" model to demonstrate how earthly events such as war and weather, and celestial events on the sun or Venus, could explain the business cycle.

Empiricists such as Juglar (a Jevons contemporary), Mitchell, and Persons (Moore's contemporaries) improved quantitative techniques (describing, classifying, measuring concepts, and preparing and adjusting data). But the relative roles assigned by them to theory and data led to a minority view of "measurement without theory."

Morgan illustrates continued gains in linking theory and data, developing quantitative methods, and recognizing probability by discussing several models built by Tinbergen in the mid-1930's. Strong criticism of Tinbergen, tempered by staunch support, helped to hone the methods of econometrics. Morgan closes Act I on a synthesis of mathematically expressed dynamic theory and statistical method.

In Act II, Morgan turns to a discussion of demand analysis. The scene opens on a price-quantity schedule of the demand for wheat constructed in 1699, progresses through Cournot's graphical and mathematical representations in 1838, and then shifts to a broad attack based on the idea of marginal analysis in the late 19th century.

By the early 20th century, two facts were clear. First, demand analysts had a cohesive theory that business cycle analysts did not have. Second, simple statistical fits of price-quantity data were not going to work. Demand theory assumed a static relationship with other variables constant, while data appeared in a dynamic context with other variables shifting. The apparent mismatch between theory and data led to much adjustment of data, some twisting of theory, and eventually, progress in the use of correlation and regression in the identification of supply and demand relationships, and in model specification and testing.

As Morgan closes Act II, we see that most of the important ideas about simultaneous equations, structural and reduced forms, instrumental variables, and identification of supply and demand curves lay buried in obscure books, book reviews, U.S. Department of Agriculture bulletins, and foreign language journals of the early decades of this century. Mainstream economists took little notice of the relations among economic activity, data, theory, and measurement.

In Act III, formal models of the data-theory relationship progress during the first half of this century from single equation models to mature, stepwise multiple-equation models (including the cobweb), and then to

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Edwards, an economist, served on the editorial board of this Journal from 1966 to 1989 and was editor during 1976-83.

simultaneous multiple-equation models. The complex problem is intertwined with econometric issues such as identification, simultaneity, and causality. Morgan tells how economists dealt with difficult questions: How does one resolve the conflicts that arise when the economic relationship suggested by theory does not correspond with a relationship generated from data? How does one respond to a recognition that the theoretical relationships are interdependent in a complex system while the models are relatively simple?

Act III closes with a discussion of Haavelmo's "probabilistic revolution" in econometrics. Morgan examines and explains the paradox that the theoretical basis for statistical inference lies in probability theory, yet economists using statistical methods explicitly rejected probability theory. Haavelmo's revolution changed the way economists related theory to data. It led to a method for seeking the correct choice of a model for the observed data by using statistical tests. Haavelmo made it clear that measurements through correlation and regression require no theory, but probability theory is needed to judge the quality of such measurements.

By the late 1940's, the probability revolution had taken hold of economics. One could mindlessly fit regressions, but now there was a framework for testing econometric theories. Solutions and insights from earlier work on business cycles, demand analysis, and model building fit together like the pieces of a jigsaw puzzle. Morgan credits much of this synthesis to a handful of econometricians. Her book, despite its too-frequent typographical errors and misspellings, provides a fascinating and clear story about an important period that few economists know, yet all are affected by.

It looks like a happy-ever-after ending until Morgan adds a final twist. She concludes that by the 1950's the founding ideal of econometrics, the union of mathematical and statistical economics, had collapsed. At first, her closing words shook me up and I did not want to believe them. Up to the last paragraph, the book had been a clearly told history of progress in econometric ideas, a history of concern to all readers of this journal. I was caught up in the rush of progress and was not ready to hear about regress.

But on reflection, I thought of econometricians who regard data merely as an aid for illustrating new statistical tests and methods, not as a basis for explaining real and relevant economic issues. I also thought of economic theorists who offer solutions to problems with no recourse to data. And I thought of the volumes of data used to describe but not to explain the economy. Perhaps Morgan is right. Perhaps we are back to where we started a century ago: some economists are armchair theorists, others are brute-force empiricists, and only a handful worry about building a bridge between them.

Introductory Readings in Geographic Information Systems. *Edited by Donna J. Peuquet and Duane F. Marble. New York: Taylor and Francis, 1990, 371 pages, hardcover, $88; softcover, $39.*

Reviewed by D. David Moyer

A geographic information system (GIS) is a system for handling spatially referenced data, including the computer hardware, software staff, and institutional support, that can be used to acquire, manipulate, update, analyze, and display spatial data. Use of GIS has increased sharply in the past 5 years at all levels of government because of the maturing of related technology and an increased demand for ways to handle and analyze the more than 75 percent of government data that is spatial. GIS has elevated analytical capabilities from the limitations of the manual overlays of mylar maps just a few years ago.

Work that was begun in the Economic Research Service in the 1960's has now emerged as an analytical tool in the Water Quality Section of the Resources and Technology Division, ERS. The National Oceanic and Atmospheric Administration, the Bureau of Land Management, and the Forest Service have even more ambitious programs underway. The Soil Conservation Service used GIS to develop and measure the impact of policies contained in the 1985 and 1990 Federal farm bills. Other government applications include land use planning, soil erosion control and management, and analyses of water quality and wildlife habitat suitability. This book of readings, therefore, will find a ready audience in many government agencies as planners, geographers, program managers, environmental scientists, and researchers in a wide variety of disciplines seek to improve the quality and timeliness of their work.

The compilation of a set of readings is never easy, and for a topic like GIS which is both relatively new and widely applicable, the task is doubly difficult. The book is "intended as a supplementary reader for use in an introductory, upper-division or graduate-level course in GIS, as well as for practicing professionals who wish to learn more about this technology." Further complicating the editors' problems are the wide range of source materials available. GIS information is scattered throughout a variety of reports and journals. *The URISA Journal* (of the Urban and Regional Information Systems Association), and *International Journal of Geographical Information Systems*, and *GIS World* show particular promise as gathering points for GIS-relevant literature.

The 26 papers in the book are grouped into five topics, enabling the reader to focus on or skip blocks of material. (This attention to indexing will also facilitate the use of the Peuquet and Marble text as a reference.) Each of the five major parts begins with a 2-3 page introduction that attempts to integrate the papers in the section, and provides a list of additional references on the topics covered. This should help those readers without a companion textbook.

The editors have provided a number of guides to making efficient use of the material. The Preface and Introduction summarize the needs and uses of GIS, organizing the entire book by general subjects and particular papers. The usefulness of each section will depend on the background of the reader.

Those wanting an overview of GIS will appreciate the articles that define GIS. An article by Tomlinson crisply recounts the 20-year history of GIS and alerts developers of GIS to potential problem areas. Jack Dangermond gives both narrative and graphic descriptions of analytical and data processing functions typically performed in a GIS. The reader should find the graphics here particularly helpful.

Part II, more than one-third of the book, describes several GIS applications. Of interest to anyone analyzing 1990 Census data are the three papers on the DIME and TIGER data bases that were developed by the U.S. Bureau of the Census. Given the interest in using the TIGER files as a data base for GIS, the discussions by Marx and Sobel will be especially welcome. They describe how the TIGER system was built, linking U.S. Geological Survey 1:100,000 map data with Census attribute data, to produce an "integrated geographic data base for the entire United States." It seems likely that this database, combined with appropriate GIS software, will indeed "form the basis for much of the urban [and rural] spatial data processing in the 1990's."

Shorter parts of the book concern the problems in building a database (Part III), the internal workings of a GIS, including data representation and analysis techniques (Part IV), and materials to aid those who must design or evaluate GIS for use in their agency or business. Here Vrana raises the issue of temporal data, a topic largely ignored in the GIS community until very recently. Vrana's discussion of three prototype land information systems, the common themes and problems, should help many economists, planners, and geographers in ERS as well as other agencies. The

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discussion of the importance of the temporal dimension of land data for resource management, land ownership, and land use planning is especially helpful.

The editors concede that some of the material, even on data bases and data representation, will become dated fairly quickly. An update in the form of a postscript or an introduction to the papers would have mitigated this. For example, in the applications section, the editors include a long 1979 paper on the MAGI (Maryland Automated Geographic Information) system. An update could include the MAGI's current operating status, its evolving applications, updated cost data, software changes, and conversion problems. Not only would this information answer the questions that would arise in the reader's mind, but would add longevity to the book and aid the reader in comprehending the rapidly changing field of GIS.

As in most compilations, readers will find that style, readability, and amount of background assumed by the author varies with each paper. This inconvenience pales next to the book's reference value to the relative newcomer to GIS, as well as to the more experienced and inquisitive analyst. GIS not only provides a powerful tool in resource policy questions, it also will restructure many government and private institutions that manage natural resources.

Too Slow To Act? Objective Analysis Needed

The Farm Debt Crisis of the 1980's. By Neil E. Harl. Ames: Iowa State University Press, 1990, 350 pages, $24.95.

Reviewed by Douglas Duncan and Steven Koenig

Neil Harl takes center stage in this memoir of his experiences during the mid-1980's financial crunch in agriculture. His behind-the-scenes account of events and his frank opinions of other players in the crisis is engaging. However, this book suffers from an attempt to exceed the bounds of memoir and serve as policy analysis as well. Readers expecting a rigorous and objective analysis of what has come to be called "the farm debt crisis of the 1980's" will be disappointed.

The first two chapters, "The Gathering Storm" and "The Slow Realization of Disaster for Agriculture," portend the farm crisis and the author's role in it. Harl hypothesizes a set of causes, though the weight placed on each is likely to be disputed by some economists familiar with the period and circumstances.

In chapter one, Harl roots the farm debt crisis in three Federal policies that economically handicapped agriculture in the 1980's: (1) an accommodative inflationary monetary policy in previous decades and the resultant low real cost of capital, which encouraged leveraging of investments; (2) the change in Federal Reserve Monetary Policy, which drove interest rates up, leading to the appreciation of the U.S. dollar and a subsequent decline in U.S. farm exports; and (3) the Economic Recovery Tax Act (ERTA) of 1981 and the ensuing growth of the Federal deficit.

Of these three suggested causes, the third is perhaps the least convincing. Harl fails to provide evidence that would measure the burden of changes in the deficit and interest rates on farmers. Indeed, the first stage of the ERTA tax cuts (which went into effect over 3 years beginning in 1981), roughly coincides with the peak in interest rates. Interest rates declined, though, as the two subsequent stages of ERTA took effect and the deficit grew. Farmers' financial hardships occurred over the same time period, but does this simple correlation mean a causal relationship? In fact, the linkage between deficits and interest rates remains the source of empirical debate among economists.

Harl feels the agricultural sector should be shielded from the macroeconomy and harmful Federal policies. Agriculture, he contends, is a capital-intensive industry, dependent on debt capital, and hence, particularly vulnerable to policy changes and macroeconomic events. His special-case argument is unconvincing, oft-cited as it is by other sectors of the economy. His message is clear, however: the Federal Government must take a strong and active role in insulating the farm economy.

Underlying this general call for government protection and the adoption of his specific proposal are one of two possibilities regarding Harl's view of economic efficiency: (1) the role of markets in generating economic efficiency is not understood, or (2) efficiency is overridden by political expediency.

While Harl acknowledges that farm debt was concentrated in the hands of just a few farmers, he denies that those highly indebted farmers might have made poor investment decisions or were acting as speculators. He clearly states that they were victims of circumstance, and therefore deserving of government support.

Empirical research is suggested in chapter 10, "Lessons Learned," as the philosophical, practical, and empirical points of debate are organized into 12 lessons. In addition to "Lesson 1: The Danger of Aberrational Conditions," at least four others can be addressed empirically: "The Capacity of Creditors to Broker Losses," "Vulnerability of Agriculture to High Interest Rates," "The Hazards of Nondiversity in Loan Portfolios," and "The Farm Crisis as a Systems Problem for the Entire Community."

A summary of the empirical research in each of the above areas would have added analytically to the book. Research results have not generated a consensus among agricultural economists in any of these areas, but the crisis has only recently passed and a post-crisis evaluation of data should further our understanding of these events.

One section brings up a topic that needs public discussion: "The Need for a Team Effort by USDA and State Universities." The author's tone here and elsewhere implies that failure to adopt his view of conditions and solutions constitutes a lack of cooperation. This is perhaps a misunderstanding of USDA's and the public universities' different roles, roles that have changed along with the agricultural sector.

Despite the differing masters served by these institutions, the personnel that staff them have the same skills and should be able to work together. The aggregate policy-oriented perspective of USDA can combine with the narrower State-level focus of university experiment stations and extension services in areas of common interest.

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As a memoir, the book may have been written too soon to allow for the seasoning of personal perspective and the playing out of subsequent events. The author devotes much of the book (most of chapters 3-9) to his intense personal struggle, first to convince political leaders, college economists, and slumbering government officials of "the greatest crisis for farmers since the 1930's," then to persuade everyone to adopt his solutions. Harl dramatizes some events to enhance their historical appeal, switching hats quickly from social historian to policy advocate.

The events of the farm crisis are not presented chronologically but solipsistically, yielding a very close view of one university economist's participation in the policymaking process. This tack may appeal to political scientists and students of agricultural policy formation, but those unfamiliar with the duration of the crisis may be confused. Readers will find that much of the book's analysis and storyline is centered on Iowa, limiting its historical value.

Economic events are not analyzed empirically, and this deters us from sympathizing with the author or trusting his conclusions. The characterization of those with differing views as having a "remarkable capacity for limited vision of problems" (p. 78) implies that reasonable people cannot hold differing views and is offensive. A further stylistic point that hinders readability is the frequent reference to documents "on file at the ISU Parks Library," all of which should have been endnoted.

The first of Harl's two proposals to handle the farm debt crisis is debt restructuring, where lenders would forgive up to 20 percent of principal debt in return for a Federal guarantee on the remaining debt. Chapter 3 is mostly devoted to the selling of this proposal to policymakers, the media, lenders, and farmers. This chapter is the first to rely heavily on the print media *(The Des Moines Register* and *The Wall Street Journal)* to document and analyze the farm debt crisis.

Debt restructuring did eventually surface in the fall of 1984 as a Presidential initiative. The Debt Adjustment Program offered Federal guarantees on certain troubled loans if the lender forgave 10 percent of outstanding debt. However, demand for the program was weak with only 817 loans guaranteed by program's end in 1989.

Harl's second bold initiative to save agriculture was the Agricultural Credit Corporation (chapter 5), which would acquire farmland and machinery from failing farmers at "fair market value" and then rent these assets back to farmers, with former owners given preference to rent and repurchase. A financing component would provide interest rate assistance and capital to financially troubled farmers.

This second initiative affirms Harl's belief that farmland values must be upheld at all costs. He even cites an exchange of letters with a young farmer who argues that land prices are only falling to the point of economic efficiency. Harl appears unwilling to recognize that land values had gotten out of line with economic returns and that adjustments were needed and inevitable. Lenders who based farm loan repayment on capital appreciation and not cash flow ultimately paid the price.

Harl indicts the Federal Government in chapter 6 ("Indifference in Washington") for its lax response time and bureaucratic insensitivity. He recounts policy sessions with top officials from the Office of Management and Budget, the U.S. Department of Agriculture, the Federal Reserve Board, and the Congress. Even the Agriculture Department's Economic Research Service does not escape criticism for failing to arouse Washington to the financial problems of agriculture. Harl's naivete of the agricultural policymaking process is evident here. Interestingly, the importance of the Farmers Home Administration, the Federal lender of last resort to farmers, is largely sidestepped. The agency provided the bulk of targeted Federal assistance to financially strapped farmers. Untargeted assistance to the farm sector, through commodity income and price support programs, totaled over $133 billion during the 1980's, a figure the author neglects to mention until the last chapter.

The author lionizes the media's coverage of the farm debt crisis in a tedious and redundant chapter 9. His estimation of the hardship as "one of the most poignant and emotional news stories of the century" (p. 268) seeks to justify the media blitz and cements Harl's symbiotic relationship with the local Iowa press, evident throughout the book. The media, in the reviewers' opinion, exhibited much naivete in sentimentalizing rather than impartially analyzing the farmers' financial plight.

The book should stimulate discussion of the appropriate role of Federal and State governments, State universities, and private sector interest groups in characterizing economic problems and intervening in agricultural markets. Unfortunately, neither the postulated causes of the crisis nor its extent are empirically verified, throwing into question a chapter entitled "Lessons Learned."

As a memoir, a breadth of focus in line with the book's title would be more satisfying than the adopted parochial focus on Iowa. A more careful chronological structuring of the text along with elimination of redundancies such as the media's role would help. Finally, the book may have been written too soon for events to be placed in proper historical perspective.

Agricultural Price Policy: A Practitioner's Guide to Partial-Equilibrium Analysis. By Isabelle Tsakok. Ithaca, NY: Cornell Univ. Press, 1990, 305 pages, $19.95 (softcover).

Reviewed by Milton H. Ericksen

JAER reminds reviewers in its instructions that, "Books are numerous, time is short. How important is it that we should read this one?" In my opinion, Tsakok's book is important only to those about to tackle a painstakingly detailed analysis of prices in a developing economy. In the absence of a specific project, reading this book is akin to reading a shop manual for a car not yet purchased or even fully considered. As a shop manual, Tsakok's guide succeeds, thorough in its explanation of how to assemble price information pertaining to border and internal prices, how to adjust these price series, and how to calibrate ratios and measures from the assembled prices.

However, in spite of the book's detail and excellent tips, the practical instructions are not connected to specific objectives that would derive from the price measures discussed. The foreword alone points out that the tools of partial-equilibrium analysis can improve economic policies in the name of resource efficiency, and "induce a configuration of investments that will lead to more rapid economic growth."

Opportunity cost and comparative advantage form the theoretical basis for a battery of measures, such as shadow exchange rate, effective exchange rate, a consumption conversion factor, a capital conversion factor, a nominal protection coefficient, an effective protection coefficient, an effective subsidy coefficient, a producer subsidy equivalent, a consumer subsidy equivalent, a domestic resource cost, a net economic benefit, and an opportunity cost of capital. However, Tsakok assumes prior knowledge of these concepts, making the book a marginal classroom reference. And while conceptual development of opportunity cost, comparative advantage, and elasticities is not ignored, it is not complete enough to make the book a definitive tool.

The book's preface and first two chapters indicate an eventual analysis of price policies in developing countries, how they have distorted efficient resource allocation, and how specific policy changes may improve efficiency. However, Tsakok stays with the mechanics of deriving measures. Tsakok alludes to, but never presents, the price-centered, partial-equilibrium analysis that might enlighten policymakers.

I found the book finally lacking. It was not in the explanation of points and examples, which are sometimes detailed to the point of tedium. Many sentences make obvious points: "Strictly defined, a *tradable* good is a commodity or service that can be imported or exported, and a *nontradable* good is one that cannot be imported or exported." Nor does the book lack in accuracy. But what problems would require that a practitioner or analyst (terms used throughout the book) undertake an analysis, and to what practical use could the derived measures be put?

If the reader is already examining the efficiency or comparative advantage of a developing economy that is "small" in international trade, this book could be helpful. For those without an agenda or an end beyond methodology, the book will not suggest any.

Ericksen is an agricultural economist with the Office of the Administrator, ERS.

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